

Biology

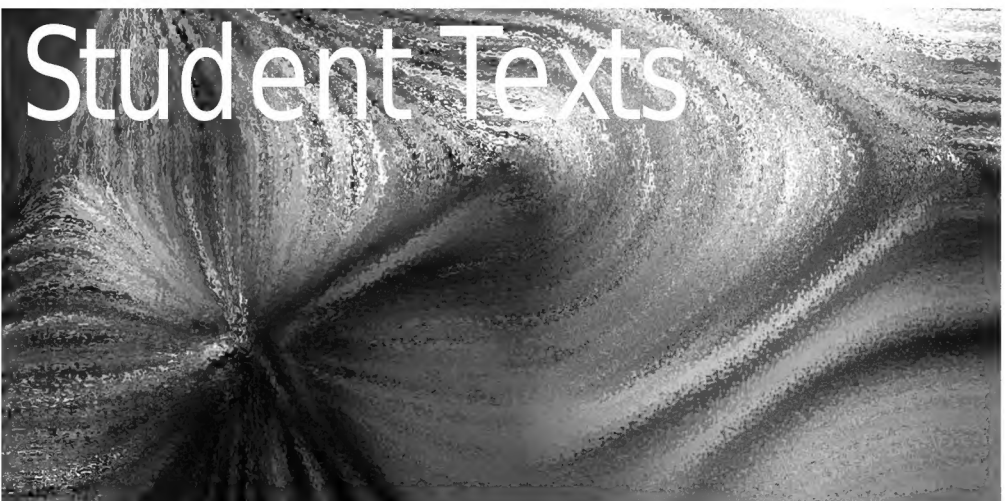
Teaching Resource

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FELTHAM PRESS

Biology or Biology (Human)



Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

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Biology or Biology (Human)

Student Text



Unit 1 Molecules and Cells

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Unit 1

Molecules and Cells

Contents

1.1 Molecules	1
▼ The structure and properties of some important biological molecules	
▼ Water	
▼ Carbohydrates	
▼ Lipids	
▼ Proteins	
▼ Nucleic acids	
1.2 Enzymes	29
1.3 Cellular Organisation	37
▼ Prokaryotic cells	
▼ Eukaryotic cells	
▼ Transport across membranes	
▼ Aggregations of cells	
1.4 The Cell Cycle	57
▼ Chromosome structure	
▼ Mitosis	

1.1

Molecules

Content

The structure and properties of some important biological molecules

Water

- ▼ Its dipolar nature and formation of hydrogen bonds
- ▼ The importance of water as a solvent
- ▼ Other roles of water related to its high latent heat of vaporisation, specific heat capacity, density and surface tension.

Carbohydrates

- ▼ Hexoses and pentoses are monosaccharides and their role as monomers
- ▼ The structure and roles of the monosaccharides alpha and beta glucose, ribose and deoxyribose
- ▼ The roles of fructose and galactose
- ▼ Disaccharides and polysaccharides composed of monomers joined by glycosidic bonds
- ▼ Condensation and hydrolysis reactions involved in the synthesis and degradation of disaccharides and polysaccharides
- ▼ The structure and roles of the disaccharides sucrose, maltose and lactose
- ▼ The structure and roles of the polysaccharides starch (amylose and amylopectin), cellulose and glycogen

Lipids

- ▼ The general nature of lipids as fats, oils and waxes
- ▼ The general structure of a triglyceride synthesised from glycerol and fatty acids, the formation of ester bonds
- ▼ The nature of saturated and unsaturated fatty acids
- ▼ The roles of lipids as energy stores, and in protection, waterproofing, insulation and buoyancy
- ▼ The structure and properties of phospholipids and their role in the structure and properties of cell membranes

Proteins

- ▼ The nature of amino acids as monomers in the formation of polypeptides and proteins
- ▼ The general formula and general structure of amino acids
- ▼ The formation of a peptide bond
- ▼ The meaning of the terms primary, secondary, tertiary and quaternary structure and their importance in the structure of enzymes
- ▼ Condensation and hydrolysis reactions in the synthesis and degradation of polypeptides and proteins
- ▼ The role of ionic, hydrogen and disulphide bonds in the structure of proteins as illustrated by insulin and collagen
- ▼ The nature and roles of fibrous and globular proteins as illustrated by collagen and insulin

Nucleic acids

- ▼ Ribonucleic acid (RNA) and deoxyribonucleic acid (DNA) as polynucleotides composed of mononucleotides
- ▼ The basic structure of a mononucleotide
- ▼ Thymine, uracil and cytosine as pyrimidines; adenine and guanine as purines
- ▼ Condensation reactions in the formation of mononucleotides and polynucleotides (DNA and RNA)
- ▼ The structure and roles of messenger and transfer RNA
- ▼ The structure of DNA, base pairing; the double helix
- ▼ The mechanism of replication of DNA (semi-conservative)
- ▼ The nature of the genetic code, the gene as a sequence of bases on the DNA molecule which codes for a sequence of amino acids in a polypeptide chain
- ▼ The processes of transcription and translation in the synthesis of proteins; amino acid sequences are specified by DNA
- ▼ The function of the ribosomes
- ▼ Codons and anticodons in relation to messenger and transfer RNA
- ▼ The Human Genome Project
- ▼ (Practical work to include qualitative and quantitative biochemical tests for starch, reducing and non-reducing sugars and proteins using iodine solution, Benedict's reagent and biuret reagent, as appropriate)

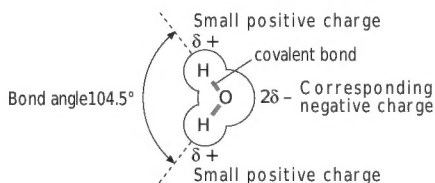
Introduction

It may surprise you to know that the bodies of living organisms are made up of fewer than 20 different chemical elements and just six of these bioelements make up 99% of the total body mass (oxygen 65%, carbon 18%, hydrogen 10%, nitrogen 3%, calcium 2%, phosphorus 1%). Most of the important biological molecules (apart from the most important of all - water) are organic, which means that they are made up from carbon compounds (note that most but not all compounds containing carbon are organic. Exceptions include carbon dioxide and carbonates). Organic biomolecules include carbohydrates, proteins, lipids and nucleic acids, all of which exist as individual sub-units (**monomers**) or repeating chains of sub-units (**polymers**). Polymers are very large molecules, built up by reactions called **condensation reactions** in which a molecule of water is lost as each sub-unit joins the next. They may be broken down by the reverse process, **hydrolysis**, which involves the addition of a molecule of water for each bond broken. The following account describes the structure of carbohydrates, proteins and lipids and the relationship of molecular structure to their function in living organisms.

WATER

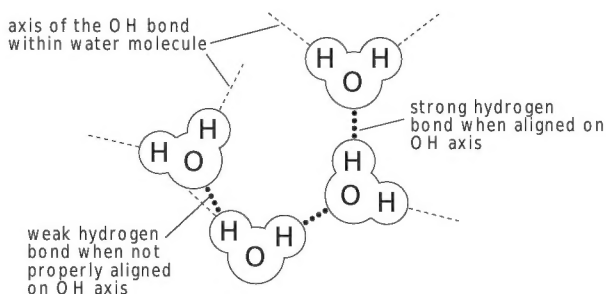
Almost everyone 'knows' the chemical formula for water - H_2O . It is a molecule made up of two hydrogen atoms combined with a single oxygen atom. As molecules go H_2O appears rather simple, yet its molecular structure results in many unique properties upon which life depends.

Each hydrogen atom combines with the oxygen atom by means of a pair of shared electrons (covalent bond). The nucleus of the oxygen atom has a strong positive charge which tends to pull the negatively charged electrons away from the smaller hydrogen atoms. As a result, a negative charge develops near the oxygen atom and positive charges occur near the hydrogen atoms. Molecules which have charged regions are called polar molecules. Water has both positive and negative charges and is therefore described as **dipolar**.



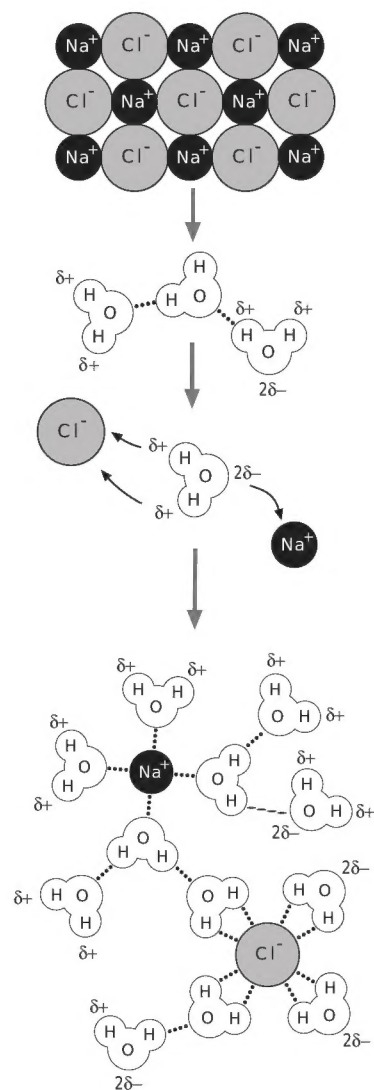
Electron distribution within the water molecule causes the oxygen end of the molecule to have a partial negative charge and the hydrogen sites to have a partial positive charge

The positive and negative charges cause water molecules to attract each other by means of relatively loose linkages called **hydrogen bonds** (H-bonds). This mutual attraction explains why water is a liquid at standard temperature and pressure (STP), whereas other, similar sized, non-polar molecules like methane (CH_4), ammonia (NH_3) and hydrogen sulphide (H_2S) are gases. The H-bonds in water are broken when energy is supplied, e.g. when water is heated. When they break the liquid becomes a gas (vapour). At and below 0°C the H-bonds are at their shortest and strongest and lined up to form a tight regular crystalline structure which is ice. Crucially for life on earth, ice is less dense or 'lighter' than liquid water; in other words ice floats, and aquatic organisms are protected beneath an insulating layer of surface ice. If it did not, and water froze from the bottom up, aquatic organisms would be exposed in progressively shallow surface waters.



Water molecules also attract other polar molecules. When mixed with salt (NaCl), for example, electrostatic links are made between the positive and negative charges of the salt and the water. Water is an excellent solvent allowing many molecules and charged ions to be held in cells and transported around the body. Any molecule with a polar region will dissolve, including sugars and alcohol, and water molecules gather around large protein molecules to form a special kind of solution called a **colloid**, as found in the cytoplasm of cells.

Molecular model of water solubility



Unit 1: Molecules and Cells

As you have seen, the chemical structure of water determines its properties. The table below lists these properties with examples of their biological importance.

Property	Example of biological importance
State	Solid (ice) at 0°C and vapour above 100°C (at sea level), providing a wide range of temperature at which it exists as a liquid.
Solvent	'Universal' solvent in which many substances dissolve.
Density	Water supports aquatic organisms. Ice is less dense than water, therefore ice floats and organisms can survive beneath it.
Viscosity	Allows free flow for transport of materials inside and outside of organisms.
Surface Tension	Water has a strong surface film allowing small organisms to be supported on top or underneath it
Capillarity	Water rises in small bore tubes against the pull of gravity because the polar water molecules are attracted to themselves and to a number of surfaces. Capillarity is important in water transport in plants.
Incompressibility	Water provides a hydrostatic skeleton. When enclosed in any structure with a strong surrounding wall, water provides much support and protection to structures within it - e.g. earthworm body cavity, human abdominal cavity
Latent heat of vaporisation	As water molecules evaporate they absorb heat energy from the surface from which they are evaporating, cooling them down in the process, e.g. sweating.
Specific heat	Water has a high specific heat. This means that it gains and loses heat slowly which is important in the temperature control of aquatic environments and internal fluids.
Transparent	Allows the transmission of light e.g. for photosynthesis in aquatic organisms.

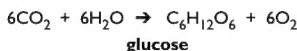
◆ CHECKPOINT SUMMARY

- ◆ *Water molecules are dipolar with an electronegative pole and an electropositive pole*
- ◆ *The dipolar nature of water causes molecules to be attracted to each other by hydrogen bonds resulting in most of the key properties of water in relation to living organisms*
- ◆ *Liquid at normal temperature and pressures, solid (ice) at 0°C, boiling point 100°C, providing a wide range as a liquid*
- ◆ *It has high cohesion resulting in a strong surface film allowing small organisms to be supported on top or underneath it, and the ability for the water column*
- ◆ *'Universal' solvent in which many substances dissolve*
- ◆ *Water supports aquatic organisms, ice is less dense than water, therefore ice floats and organisms can survive beneath it*
- ◆ *Low viscosity allows free flow for transport of materials inside and outside of organisms*
- ◆ *Water rises in small bore tubes by capillarity e.g. important in water transport in plants*
- ◆ *Being incompressible water provides a hydrostatic skeleton, e.g. earthworm body cavity, human abdominal cavity*
- ◆ *Latent heat of evaporation results in a cooling process e.g. sweating*
- ◆ *Water has a high specific heat which is important in temperature control of aquatic environments and internal fluids*
- ◆ *Transparency allows the transmission of light e.g. for photosynthesis*
- ◆ *Inorganic ions dissolve freely in water and have a wide and varied role in living organisms.*

CARBOHYDRATES

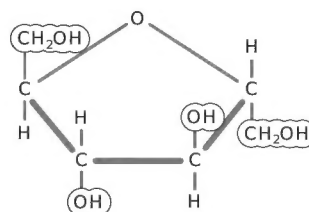
Monosaccharides

Carbohydrates are a family of molecules made up, as the name suggests, from carbon and the components of water (hydrogen and oxygen). Carbohydrates are manufactured by plants and are passed on to other organisms via food chains. You should already be familiar with the name and chemical formula of one of the simpler carbohydrate molecules, glucose, which is made from CO_2 and H_2O in the process of photosynthesis.

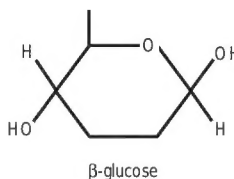
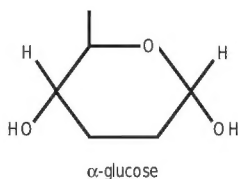
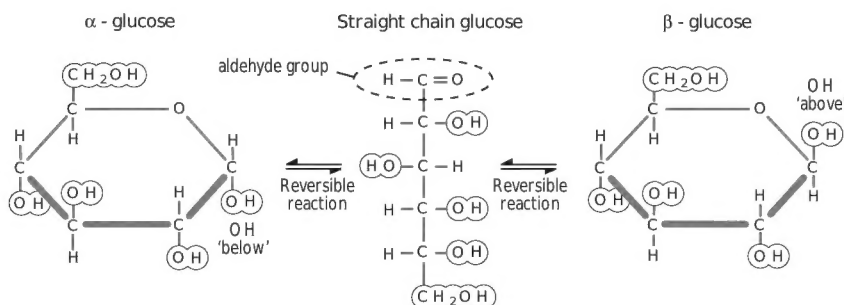


Glucose has six carbon atoms in the form of a framework to which the oxygen and hydrogen atoms are attached. In dry glucose powder the carbon atoms are arranged in a straight chain, but if it is dissolved in water, the chains form themselves into ring structures. Two different ring forms exist called **alpha** (α) **glucose** and **beta** (β) **glucose**. The carbon atoms are numbered 1 to 6 starting in a clockwise direction from the position of the oxygen atom. As discussed later, the different structures of alpha and beta glucose result in the formation of polysaccharides with different properties.

Alpha and beta glucose are **isomers**; they have the same chemical formula but a slightly different arrangement of atoms in the molecule. Fructose and galactose are also isomers of glucose. You will notice that fructose has the same number of carbon, hydrogen and oxygen atoms as glucose but it has a keto group ($\text{C}=\text{O}$) instead of the aldehyde group (CHO). This gives fructose slightly different chemical properties, for example it is sweeter than glucose.



Fructose

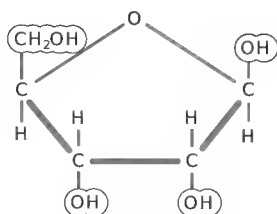


Glucose, fructose and galactose are molecules containing six carbon atoms; they are six carbon sugars called **hexoses**. The simplest carbohydrates are **trioses** (they have three carbon atoms), one example of which, **glyceraldehyde**, you will encounter later in this unit, they do not exist as free sugars but are very important intermediates in biochemical pathways. A very important group of monosaccharides has five carbons. These are the **pentoses**, and they include **ribose** and **deoxyribose** which play an essential role in the structure of RNA and DNA.

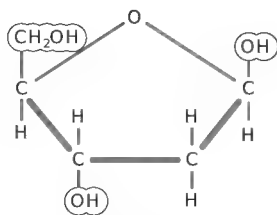
These monosaccharides: hexoses and pentoses have a role as monomers in long chain molecules known as polymers. Mono, di and polysaccharides may be interconverted from one form to another by condensation, hydrolysis and isomerisation reactions, each particular reaction being catalysed in living cells by enzymes.

The condensation of monosaccharides to form disaccharides and polysaccharides

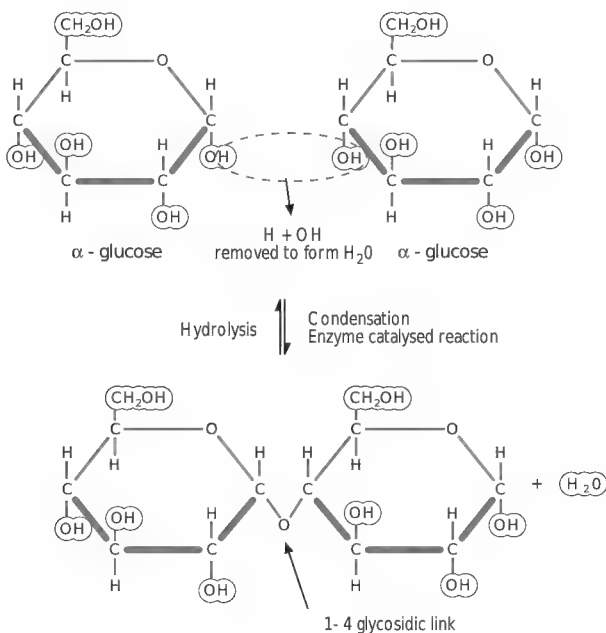
Ring structures like these are monomers which are able to link together to form pairs or long chain molecules (polymers). The terms monosaccharide, disaccharide and polysaccharide are used to describe the number of glucose molecules making up a chain (mono = 1, di = 2, and poly = many). If the units of glucose link up to form larger molecules, the first carbon atom of one alpha glucose molecule links to the fourth carbon atom of another with the elimination of a molecule of water. This enzyme controlled reaction results in an oxygen bridge called a **glycosidic bond**. The formation of more than one bond by condensation leads to longer and longer 'multi-molecules' or polymers.



Ribose



Deoxyribose



Hydrolysis of disaccharides and polysaccharides

Most of the carbohydrate taken in by animals as food is in the form of polysaccharides or disaccharides. In the process of digestion, enzymes catalyse the hydrolysis of glycosidic bonds to produce monosaccharides which are then absorbed into the blood. A similar process occurs in the germination of seeds. Seeds often store the polysaccharide starch which must be converted to glucose to provide the energy required for growth. The onset of germination is marked by the uptake of water, followed by the activation and release of hydrolysing enzymes.

The hydrolysis of polysaccharides in industry is achieved in two or three stages, each requiring a specific enzyme. This is illustrated by the commercial production of the glucose / fructose sweetener for soft drinks from low cost corn (maize) starch. A number of enzymes are used in this process, e.g.:

- ▼ alpha amylase which breaks down starch to shorter, branched amylopectin chains called dextrins;
- ▼ glucoamylase which hydrolyses dextrins to glucose.
- ▼ glucose isomerase which converts glucose into a glucose/fructose mixture which is sweeter than glucose alone.

Hydrolysing enzymes are used widely in the food industry. Another ingenious example is the use of the enzyme invertase in the manufacture of soft centred chocolates like after eight mints. The minty centres are made from a thick sucrose paste with mint flavouring, and just before the chocolate coat is added, a small quantity of invertase is added which slowly hydrolyses the sucrose to a semi-liquid glucose fructose mix after the chocolate has set hard.

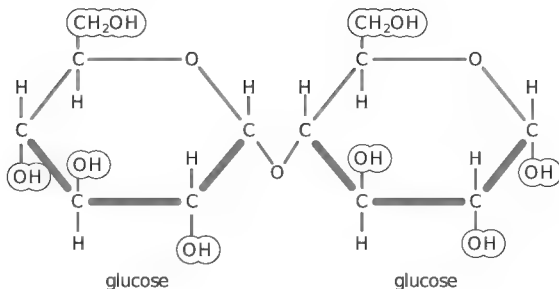
Disaccharides: maltose, sucrose and lactose

Maltose is a disaccharide formed from two molecules of alpha glucose, linked by an alpha 1-4 glycosidic bond, it is the first breakdown product of the action of amylase on starch. It derives its name from germinating barley (malt) used in the brewing industry as a source of sugars for fermentation into alcohol. The germinating barley activates amylase enzymes which hydrolyse its starch stores to maltose.

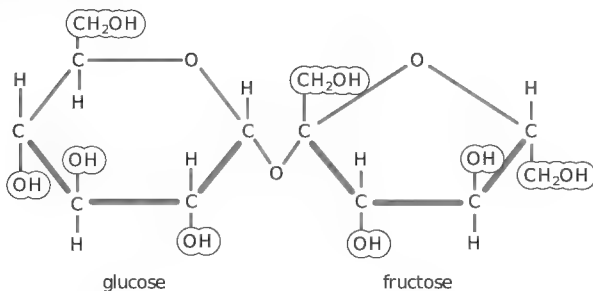
Sucrose is formed by a similar condensation reaction between a molecule of glucose and a molecule of fructose. Sucrose is the best known disaccharide because it is the sugar most produced by plants, and is the commonest sugar used to sweeten foods, being commonly known as 'table sugar'.

Lactose is sometimes referred to as a milk sugar because it is present in the milk of mammals and is, consequently, essential in the diet of infants. Lactose is a disaccharide made up of one molecule of glucose and one of galactose linked by a glycosidic 1-4 bond. Many people are lactose intolerant, not being able to digest (hydrolyse) it to its monosaccharides, so that it passes into the large intestine where it encourages the growth of bacteria which feed on it, resulting in the accumulation of lactic acid in the large intestine, and associated acute symptoms of discomfort.

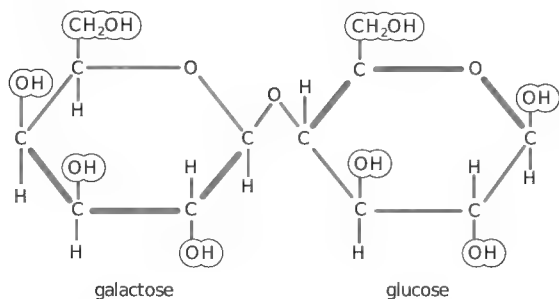
Maltose



Sucrose



Lactose



Structure and roles of the polysaccharides: starch (amylose and amylopectin), glycogen and cellulose

Glucose is the universal fuel for respiration, but it cannot be stored in cells because a high glucose concentration would result in the entry of large amounts of water by osmosis which could cause cells unprotected by a cell wall or surrounding cells, to swell up and burst. For this reason, glucose in excess of energy requirements is converted for storage to the relatively insoluble polysaccharides **starch** in plant cells and **glycogen** in animal cells. These substances are similar in chemical structure, both being formed from chains of alpha glucose molecules.

Starch is a mixture of **amylose** (unbranched chains of alpha glucose) and **amylopectin** (branched chains of alpha glucose). When combined together, the alpha glucose units have their oxygen bridges on the same side of the chain. Hydrogen bonds form between them and cause the chain to coil into a helix, so starch molecules have a dense, tightly packed structure and are relatively insoluble in water.

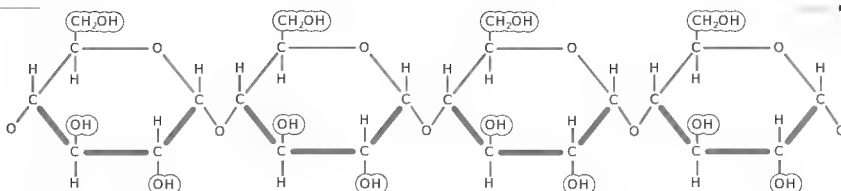
To dissolve starch, it is necessary to heat it. This breaks the hydrogen bonds and, as the coils begin to open, water molecules rush to occupy the exposed charged (polar) sites binding all over the surface. This is why starch suddenly swells in hot water and is the secret of starch based sauce thickeners used in cooking.

Glycogen has a similar structure to amylopectin but has a large number of shorter branches. It is more suited to animal metabolism as it is capable of being broken down more rapidly than starch. It is never present in food in significant amounts, due to its relatively low concentration in muscles (meat) and liver, and the fact it is rapidly broken down on the death of the cell.

CHECKPOINT SUMMARY

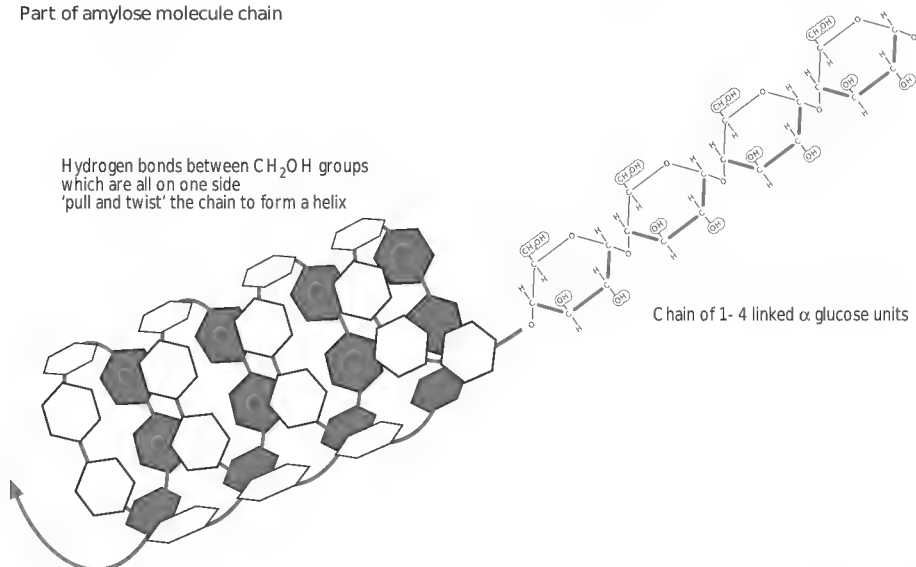
- ◆ Simplest carbohydrates are monosaccharides (single sugars) which have varying numbers of carbon atoms e.g. pentoses 5C and hexoses 6C
- ◆ Monosaccharide have a role as units (monomers) in the formation of long chains of repeating units (polymers)
- ◆ Simple formula for glucose - $C_6H_{12}O_6$
- ◆ In straight chains in dry powder form
- ◆ Forms ring structure in solution
- ◆ alpha and beta glucose are isomers differing in the 3D arrangement of their atoms
- ◆ Monosaccharides (glucose, fructose, galactose) combine with the elimination of water, form glycosidic bonds- a condensation reaction
- ◆ Glucose and fructose combine to form sucrose; glucose and galactose combine to form lactose; and two molecules of glucose combine to form maltose

Continued



Part of amylose molecule chain

Hydrogen bonds between CH_2OH groups which are all on one side 'pull and twist' the chain to form a helix



Unit 1: Molecules and Cells

Cellulose is the major component of plant cell walls. The characteristic fibrous structure of cellulose is created by chains of 1-4 linked beta glucose molecules. The beta molecules, when joined together, have their oxygen bridges on alternate sides of the chain, and thus cannot form into a helix, but by forming hydrogen bonds with other chains lying side by side they make flat ribbons which form cellulose fibres.

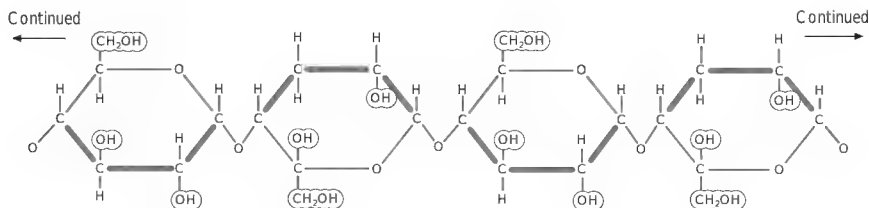
The basic meshwork of cellulose fibres in plant cell walls is strengthened and cemented by other materials such as pectin and lignin. Cellulose is the main component of numerous textiles eg cotton, linen, hemp, paper, timber products, and plastics eg celluloid.

Starch and cellulose have very different properties which arise as a result of one difference between alpha and beta glucose. Starch has no distinct structure (amorphous), no structural strength, is slightly soluble in water, and digestible by vertebrates. Cellulose has a distinct fibrous structure, great structural (tensile) strength, is insoluble in water and indigestible by vertebrates. (Herbivorous vertebrates harbour mutualistic microorganisms in specialised compartments of their gut which secrete cellulase enzyme which digests cellulose.)

CHECKPOINT SUMMARY

- ◆ Glycosidic bonds are broken by the addition of the elements of water across the bond (hydrolysis reaction)
- ◆ Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains)
- ◆ Both being long chains (polymers) of alpha glucose molecules
- ◆ When combined the alpha glucose molecules have their oxygen bridges on the same side of the chain, hydrogen bonds form between them and cause the chain to coil into a helix
- ◆ Starch molecules, relatively insoluble in water
- ◆ Glycogen ('animal starch') is a glucose polymer found in the liver and muscles of animals
- ◆ Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix, but form hydrogen bonds with other adjacent chains to make flat ribbons which form fibres.

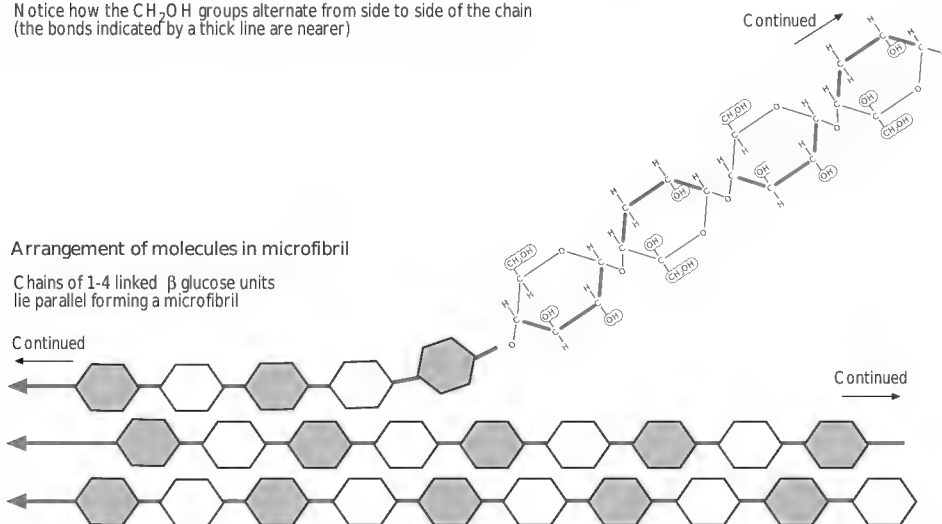
Part of a cellulose molecule chain



Notice how the CH_2OH groups alternate side to side of the chain (the bonds indicated by a thick line are nearer)

Arrangement of molecules in microfibril

Chains of 1-4 linked β glucose units lie parallel forming a microfibril



Hydrogen bonds form between alternating CH_2OH units bind molecules together side by side into microfibrils.

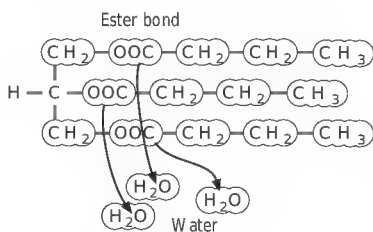
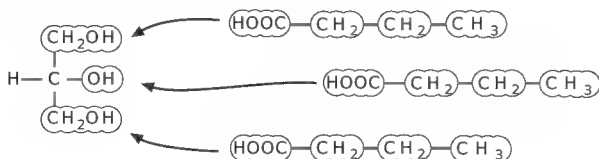
LIPIDS

Lipids are a family of molecules which include fats, oils, waxes, phospholipids and steroids. Although they vary in chemical structure they share two important characteristics: they are energy rich substances, and they are insoluble in water.

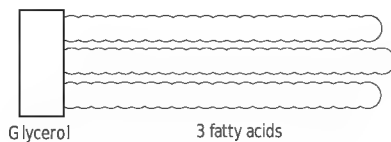
Structure and function of a triglyceride

Fats and oils are built on the same basic chemical plan which consists of a molecule of **glycerol** joined to three **fatty acid** chains. They are **triglycerides** ('mono' and 'diglycerides' are structures with one and two fatty acid chains respectively). The fatty acids are linked by **ester bonds** to glycerol in a condensation reaction similar to that seen in the formation of polysaccharides and polypeptides.

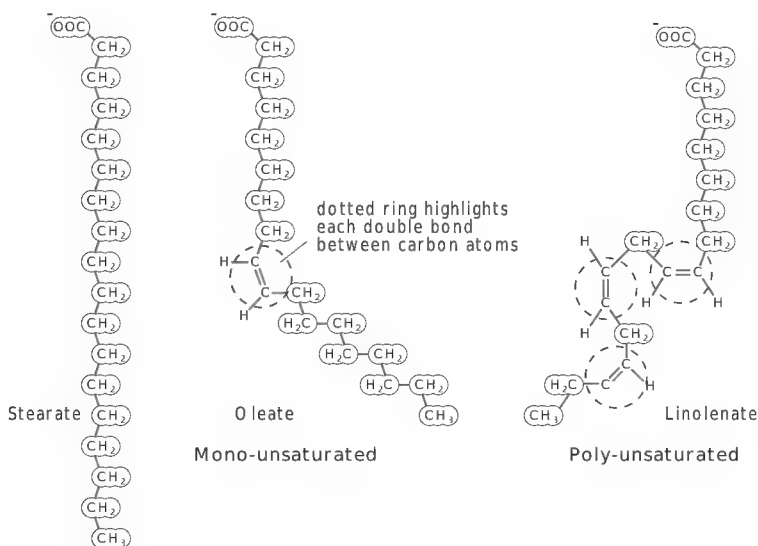
Molecular model of development of a triglyceride



Model of a triglyceride



Fatty acids are hydrocarbon chains with a carboxylic ($-\text{COOH}$) group at one end. It is the $-\text{COOH}$ group which forms the ester bond with glycerol. Hydrocarbons are non polar and, like fuel oils which have a similar structure, they contain a lot of energy locked up in their C-C and C-H bonds. Fats are mostly of animal origin and are solid at room temperature (RT); oils occur mostly in plants and are liquid at RT. The difference in melting point is due to the different nature of the hydrocarbon chains. In fats, each of the possible bonding sites between carbon and hydrogen is fully occupied (they are **saturated**), but in oils, one or more double bonds occur between the carbon atoms in the chain (they are **unsaturated**). Wherever a double bond occurs, the fatty acid chain acquires a kink, so the fatty acid chains of oils occupy more space than those of fats, giving them greater mobility and a lower melting point so that they are liquid at RT. The terms 'mono', 'di', and 'polyunsaturated' refer to the number of double bonds in the fatty acids.

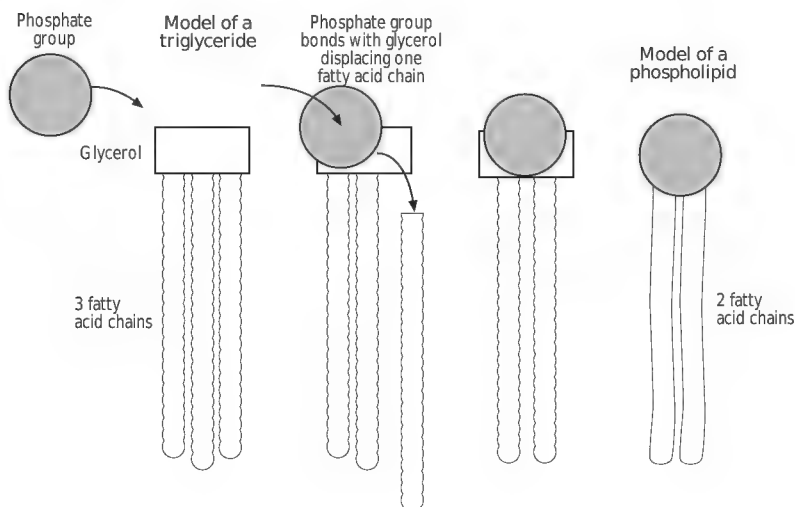


When more food energy is taken in by the body than can be used, it may be converted to fat which is stored in large adipose cells under the skin and around internal organs. **Adipose** tissue not only acts as a long term food store; it also insulates the body against rapid changes in temperature, gives mechanical protection to internal organs and, and aids buoyancy in aquatic animals.

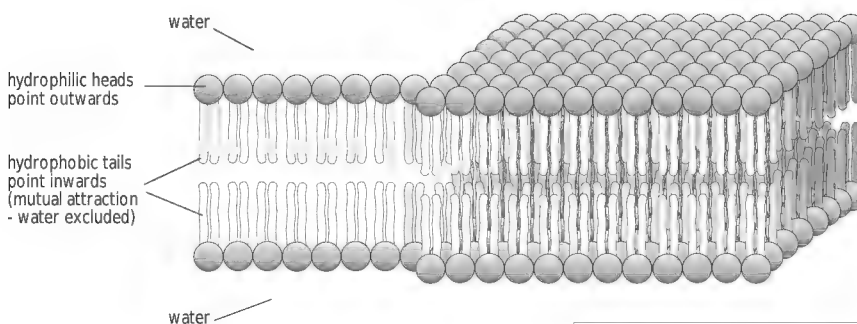
Waxes differ from fats and oils in that they have only one fatty acid chain and it is not joined to glycerol, but to a longer chain alcohol. They are produced in many animals and plants as a waterproof layer on external surfaces acting to reduce water loss (e.g the cuticle of plant leaves, and the surface layer of some insect exoskeletons).

Structure and function of a phospholipid

Phospholipids are essential to cells because they form the structural basis of all membrane systems. They have two fatty acid chains (which may be saturated or unsaturated) joined to a molecule of glycerol, the third position being occupied by a phosphate group (phosphate plus choline or ethanolamine).



The phosphate group is strongly polar and readily dissolves in water, this is the **hydrophilic** (water loving) 'head' region of phospholipids. The non polar fatty acids are repelled by water and project in the opposite direction, and these are the **hydrophobic** (water hating) 'tails'. As a result, in the presence of water, phospholipid molecules form spontaneously into a characteristic **bilayer**. It is this bilayer which forms the molecular framework of all cell membranes.



Cholesterol is another important lipid component of cell membranes although it is very different in chemical structure to the lipids so far described. It has a ring structure and belongs to a group called **steroids** which include the sex hormones testosterone and oestrogen. Cholesterol molecules are strongly hydrophobic and they take refuge between the tails of phospholipids in membranes. Their presence in the bilayer has two effects. It slows down the lateral movement of individual phospholipid molecules, making the bilayer more stable, and it prevents the movement of certain substances through the bilayer, ensuring that membrane transport occurs through the correct (protein) channels.

◆ CHECKPOINT SUMMARY

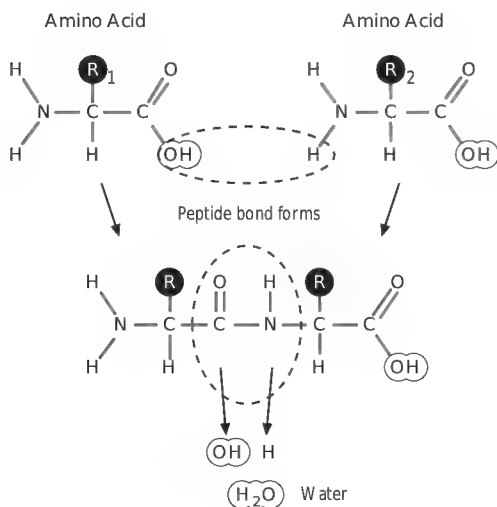
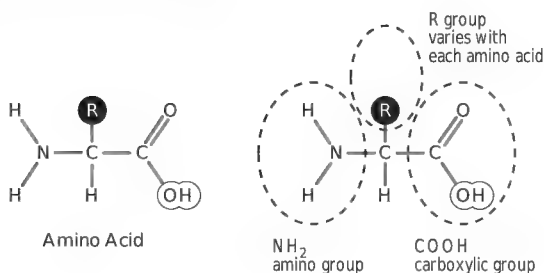
- ◆ *Lipids include fats, oils, waxes, phospholipids and steroids.*
- ◆ *Triglycerides are composed of three (tri) fatty acids combined by condensation reactions to form ester bonds with glycerol.*
- ◆ *Fatty acids have long hydrocarbon chains and a carboxyl group (COOH).*
- ◆ *Saturated fatty acids (and hence saturated fats) have no double bonds in the hydrocarbon chain which is 'saturated' with hydrogen.*
- ◆ *Unsaturated fatty acids have one double bond.*
- ◆ *Polyunsaturated fatty acids have two or more double bonds.*
- ◆ *Fats (triglycerides) are energy rich storage products in plants and animals.*
- ◆ *Lipids provide waterproofing in plant cuticles and animals e.g. insect cuticles. provide mechanical protection and insulation as sub-cutaneous fat in mammals, and buoyancy in aquatic mammals.*
- ◆ *Phospholipids are formed from triglycerides by the replacement of one fatty acid by a phosphate group.*
- ◆ *Phospholipids form the structural basis of biological membranes by forming a bilayer.*
- ◆ *The bilayer is formed with their hydrophobic poles adjacent and their hydrophilic poles in contact with the aqueous phase.*

PROTEINS

Proteins are polymers made up of **amino acids**, joined together in long chains, which may be folded and twisted in various ways. There are as many as 100 000 different kinds of protein molecule in human cells. This variety of structure is made possible by the fact that the twenty different types of amino acids commonly found in proteins can be arranged in any order in chains up to 2000 units long.

Amino acids and peptide bonds

The chemical structure of an amino acid consists of a central carbon atom bonded to a hydrogen atom, a carboxyl group ($-\text{COOH}$), an amino group ($-\text{NH}_2$), and a side chain which varies with each amino acid, referred to as the 'R' group. **Peptide bonds** form between the amino ($-\text{NH}_2$) and carboxyl ($-\text{COOH}$) groups of adjacent amino acids to make chains called peptides (dipeptide = 2 amino acids linked together, polypeptide = many amino acids). As in carbohydrates, these linkages are made by a condensation reaction involving the elimination of a molecule of water.



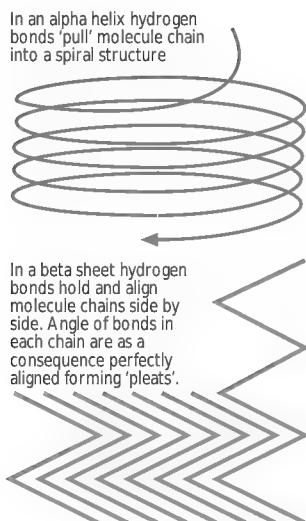
Primary structure

The amino acid sequence is the starting point or primary structure of proteins. The final shape of proteins depends upon additional bonds which form between the $-NH$, $-C=O$, and $-R$ groups which 'stick out' of the sides of the polypeptide chain.

Secondary structure

The secondary structure of proteins is determined by hydrogen bonds between adjacent $-NH$ and $-C=O$ groups. Two very different formations are possible, the **alpha helix** and **beta sheet**. Both of these secondary structures may occur in the same protein

Secondary structure of proteins



Tertiary structure

The tertiary (third level) structure of proteins is the complex 3D folding determined by bonds which form between R groups. There are three possible types depending upon the chemical properties of the different R groups. R groups may be acid, basic, polar or non polar.

The relationship of tertiary structure to function

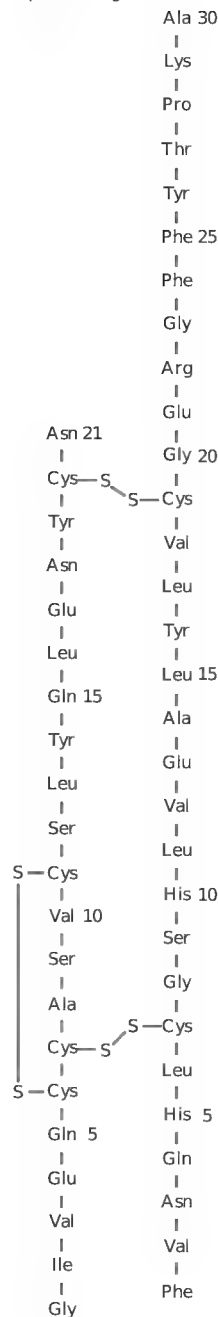
The types of bonding which hold protein molecules in position determine the shape and properties of the protein.

Hydrogen bonds are formed between polar $-R$ groups (in addition to the H-bonds already described)

Ionic bonds are formed between the negatively charged acidic $-R$ groups and positively charged basic $-R$ groups. The forces are like those which exist between the Cl^- and Na^+ ions in salt.

Hydrophobic bonds occur between the $-R$ groups of non polar amino acids e.g. valine (Val) and leucine (Leu).

Disulphide bridges



Disulphide bridges are much stronger covalent bonds formed between the sulphur atoms of the amino acid cysteine (Cys).

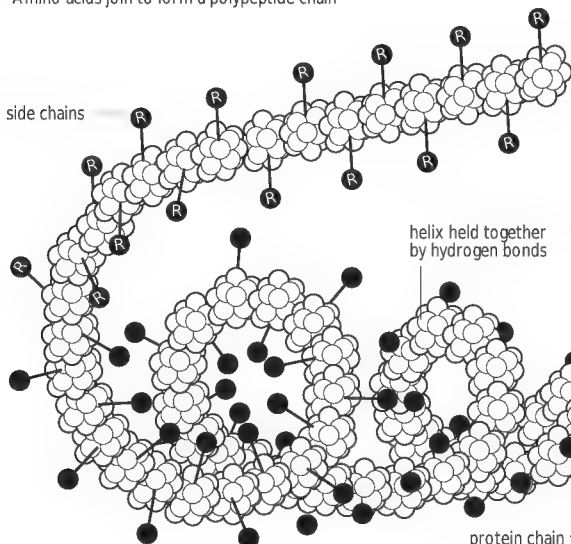
Proteins may be modified further by being linked to mineral ions, as in the case of haemoglobin or joined to carbohydrates and lipids to form **glycoproteins** and **lipoproteins**. This 'finishing off' process happens within the endoplasmic reticulum of cells.

Quaternary structure

The quaternary (fourth level) structure of proteins arises from the combination of separate polypeptide chains to form a larger complex, e.g. haemoglobin, which is composed of four polypeptide chains with iron containing haem units.

Primary structure

Amino acids join to form a polypeptide chain

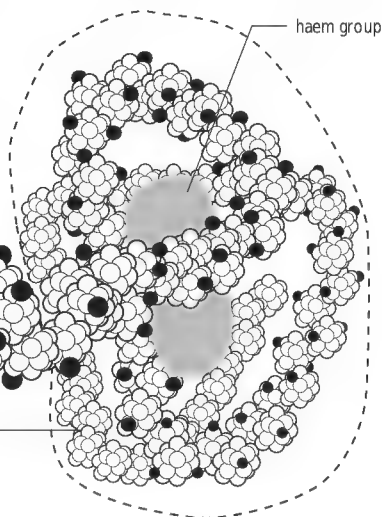


Secondary structure

Polypeptide chain folds in upon itself to form a helix

Tertiary structure

Helix folds to form compact globular unit around Haem group



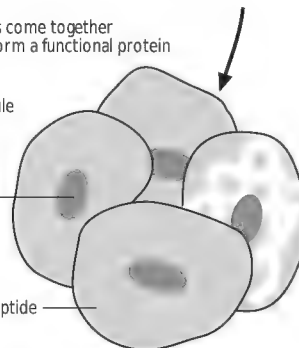
Quaternary structure

Several polypeptide chain units come together held by disulphide bridges to form a functional protein

Haemoglobin molecule has four subunits

haem group

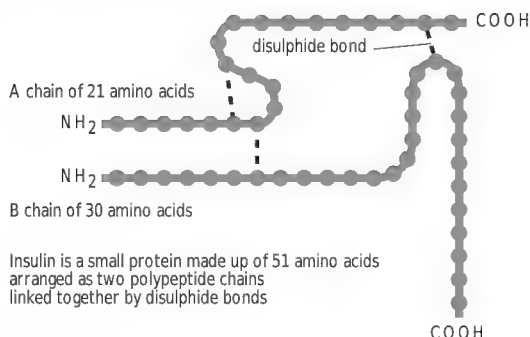
globular polypeptide subunit



Globular proteins

Globular proteins have a pronounced tertiary structure with many folds and twists, making them very susceptible to temperature and pH changes. Non polar groups tend to be repelled by water (hydrophobic) and tuck inside the molecule whilst the polar groups are attracted to water (hydrophilic) and they face outwards forming hydrogen bonds with water molecules. Globular proteins therefore tend to be soluble. Globular proteins are involved in metabolic activities e.g. enzymes, hormones, antibodies, and haemoglobin.

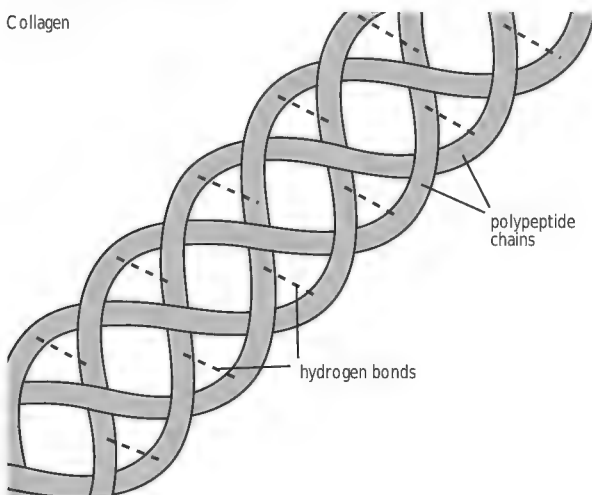
Insulin is made up of two peptide chains, one 21 amino acid units long, the other 30 units long, joined together by disulphide bridges. It is produced in the pancreas cells as a single longer chain (a **precursor** molecule) which is chopped into the two smaller pieces by a hydrolysing enzyme in a process called **activation** before being secreted into the bloodstream.



Fibrous proteins

In fibrous proteins the peptide chains are extended and inter-twined to form long thread like molecules. They do not dissolve in water and are relatively unaffected by changes in pH or temperature (they are not easily denatured). Fibrous proteins are mainly structural in function, giving support to tissues e.g. keratin in hair and skin, and collagen.

Collagen



◆ CHECKPOINT SUMMARY

- ◆ All amino acids share a common structure consisting of a hydrogen atom, an amino group (NH_2), a carboxyl acid group (COOH), and a 'R' group, all attached to a carbon atom.
- ◆ The 'R' group can range from a single hydrogen atom to a long complex chain. Thus the simplest amino acid has the formula of $\text{CH}_2\text{NH}_2\text{COOH}$.
- ◆ Amino acids combine in a condensation reaction which form a peptide bond, which is broken by hydrolysis (digestion).
- ◆ There are about 20 different types of amino acids found in proteins of living organisms.
- ◆ Proteins are polymers of up to 2000 amino acids (monomers) joined by peptide bonds (polypeptides).
- ◆ The combination of the 20 different types of amino acids gives rise to as many as 100 000 different types of proteins in living organisms.
- ◆ The sequence of amino acids in the polypeptide chain determines the primary structure of proteins.
- ◆ Hydrogen bonds between adjacent NH_2 and COOH groups result in the secondary structure of either alpha helix or beta sheet. Both of these structures may occur in the same protein.
- ◆ Bonds that form between the 'R' groups determine the tertiary structure.
- ◆ Combination or association of two or more polypeptide chains determines the quaternary structure of a protein.
- ◆ Haemoglobin has a quaternary structure involving four polypeptide chains and four iron containing haem groups.
- ◆ The three dimensional structure of protein is vital for the activity of enzymes, all of which are proteins.
- ◆ Proteins with complex tertiary and quaternary structures are referred to as globular proteins, e.g. enzymes and some hormones e.g. insulin, and are metabolically active.
- ◆ Fibrous proteins are less complex proteins and largely structural in function e.g. collagen which forms the most common connective tissue in the human body e.g. in skin, bones, tendons, etc.

Collagen is the most important structural component of skin, bone and tendons. It is the collagen in skin which forms leather after treatment in the tanning process, and it is collagen which gives bones their 'bendability'. Bone without collagen is like concrete without the reinforcing steel rods. The word 'collagen' is Greek for 'glue maker' because it was extracted from bones by boiling them up in water and used as a strong wood glue. Chemically, collagen molecules are made up of three polypeptide chains, each consisting of about 1000 amino acid units which twist around each other like the strands of a rope (a triple helix). The molecules of collagen are insoluble and have a natural tendency to link up with each other forming fibrils several millimetres long.

BIOCHEMICAL TESTS

Test for reducing sugars e.g. glucose

All the common simple carbohydrate sugars, with the notable exception of sucrose (table sugar), have the ability to **reduce** other chemicals. They are thus called reducing sugars and they can be identified by heating with **Benedict's reagent**. Benedict's reagent contains copper sulphate and has a clear light blue colour. This changes to brick red as the copper is reduced to a solid precipitate of copper oxide in the presence of a reducing sugar. The quantity of reducing sugar in a positive test can be estimated from the amount of precipitate formed using a colorimeter or a standard colour comparison sequence.

Test for non reducing sugars

Sucrose give a negative test with the Benedict's test, but when heated to boiling with dilute hydrochloric acid it is hydrolysed into its constituent monosaccharides e.g. glucose and fructose, which when made alkaline and re-tested with Benedict's reagent give a positive result.

If a mixture of both reducing and non-reducing sugars are present, which would be highly likely with plant tissue extracts, the precipitate from the initial positive Benedict's test would need to be removed by filtration, and the resultant clear filtrate re-tested for sucrose as described above.

Test for Starch

A solution of iodine in potassium iodide is added to the sample at room temperature. The presence of starch is indicated by a colour change from light brown to blue-black.

Test for Protein - the Biuret test

2cm³ of potassium hydroxide is added to 2 cm³ of the tissue extract in a test tube followed by a few drops of dilute copper sulphate solution. The presence of protein is indicated by a change in colour from light blue to purple.

◆ CHECKPOINT SUMMARY

- ◆ Generally all these tests are qualitative, i.e. the results show whether a substance is present or not.
- ◆ They are not generally quantitative, i.e. the results do not give an accurate measure of how much of the substance is present.
- ◆ The Benedict's test for reducing sugars can be semi-quantitative in so much as the colour and amount of the precipitate found in a positive test is roughly proportional to the amount of reducing sugar present. Positive results can be compared to results from solutions of known concentration of reducing sugar.
- ◆ The same considerations apply to the iodine in potassium iodide test for starch. The colour for a positive test grading from blue-black to pale brown with decreasing amounts of starch present.
- ◆ The test for lipids is physical rather than chemical, depending on the observation of the formation of an emulsion.
- ◆ The biuret test is not a simple test for proteins but is used as such by Biologists
- ◆ These tests are commonly referred to as 'Food' tests as traditionally they are used on samples of food.

NUCLEIC ACIDS

Structure of DNA and RNA

Nucleic acids are so named because they are acids found in the nucleus. They are polymers made up of repeating sub-units, in this case, **nucleotides** (mononucleotides) linking up to form a type of polymer known as a **polynucleotide**. What makes DNA so important and so unique is that it contains within its structure the genetic code, and it can produce copies of itself (replicate).

The basic structure of a mononucleotide

A mononucleotide consists of three main parts:

- ▼ a pentose (5 carbon) sugar;
- ▼ a phosphate group;
- ▼ a nitrogen-containing organic base.

There are four different types of nucleotide in DNA each with a different organic base. The bases are;

adenine (A); guanine (G), cytosine (C); and thymine (T)

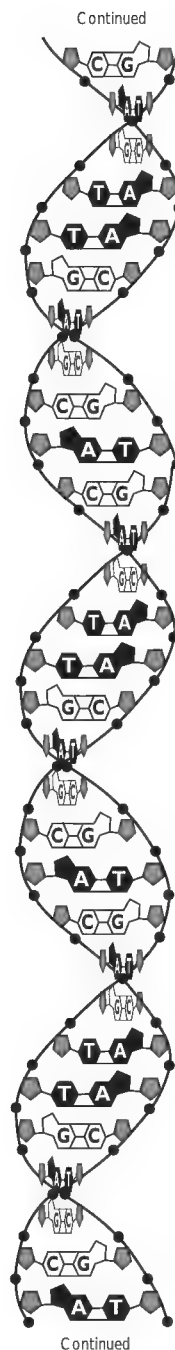
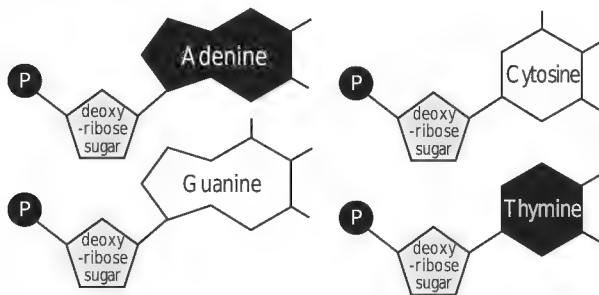
Adenine (A); guanine (G) belong to group of bases called **purines**.

Cytosine and thymine belong to a group of bases called **pyrimidines**

The components of the nucleotides are combined by condensation reactions, with the phosphate group and nitrogenous base being joined to the pentose sugar. Chains of nucleotides in turn link up by condensation reactions to form one strand of the DNA polynucleotide, with the sugar and phosphate molecules forming the 'spine' of the strand, with the bases to one side of the strand.

DNA consists of two such chains or strands linked by **hydrogen bonds** which form between pairs of bases. As the hydrogen bonds form, so the two strands of the DNA molecule twist into the spiral structure known as the double helix. Hydrogen bonds form only between specific pairs, namely A with T and C with G. The strands are therefore **complementary** to each other. The sequence along one strand determines the sequence of the other (complementary) strand. The understanding of the structure of the DNA double helix was one of the most significant breakthroughs in Biology.

The Nucleotides of DNA



RNA (Ribonucleic acid), like DNA, is a polymer made up of repeating nucleotides. It differs from DNA in the following three ways.

RNA is single stranded, not double stranded.

The pentose sugar in RNA is ribose, not deoxyribose (molecules of ribose contain an additional oxygen atom).

The pyrimidine base **uracil (U)** is found instead of thymine (T).

There are three different types of RNA, each designed to carry out a specific function in protein synthesis.

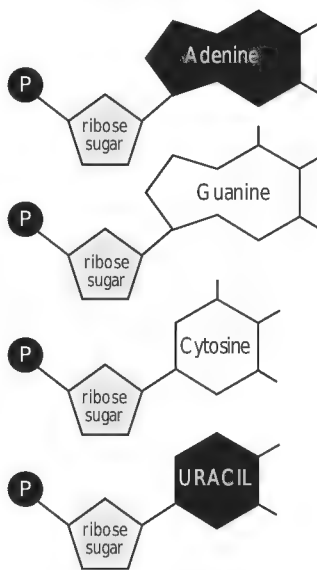
Messenger RNA (mRNA) consists of a single unfolded strand, between 75 and 3000 nucleotides long, produced in the nucleus as an exact copy of a selected section (gene) of the DNA code. The mRNA molecules travel out of the nucleus to the ribosomes where proteins (polypeptides) are synthesised.

Transfer RNA (tRNA) is between 75 and 90 nucleotides long, twisted into a characteristic shape which allows one end to attach to a specific amino acid, and the other to expose a triplet of bases called the **anti-codon** which attaches to mRNA at the site of protein (polypeptide) synthesis. tRNA molecules bring amino acids to their correct position as the protein (polypeptide) is being assembled. Each type of amino acid is carried by a different type of tRNA molecule with a specific anti-codon.

Ribosomal RNA (rRNA) consists of more than 1000 nucleotides and is found in ribosomes which are composed of an approximately equal mixture of proteins and rRNA. Ribosomal RNA is manufactured within the nucleolus of the nucleus.

The full functions of these RNAs are described in the section on the synthesis of proteins (polypeptides).

The Nucleotides of RNA

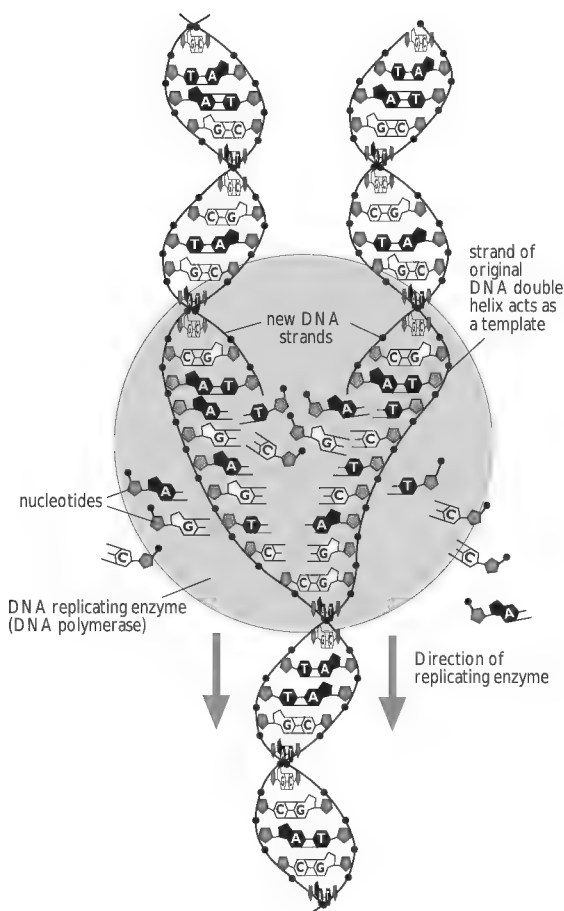


Replication of DNA

In the process of DNA replication, one double stranded DNA helix gives rise to two new DNA double stranded helices (plural of helix). To achieve this the two strands of a DNA helix unwind and separate, and each acts as a pattern (template) for the formation of another new strand. Each of the new daughter DNA molecules has one of the original strands and a new strand. For this reason, the process of replication is said to be semi-conservative, half of the original molecule is conserved in each of the two new DNA molecules. The process requires a supply of the four different types of nucleotides, energy in the form of ATP, and an enzyme called DNA polymerase. DNA polymerase is required to catalyse the condensation reactions by which free nucleotides combine to form a copy of the template strand.

Experimental evidence

for the semi-conservative mechanism of DNA replication includes experiments in which the mass of the DNA content of *Escherichia coli* (a bacterium), grown on different nutrient media was determined and compared. One batch of microorganisms was cultured on a medium containing a 'heavy' isotope of nitrogen (^{15}N), the DNA was extracted and compared with that of organisms cultured on a medium containing normal 'light' nitrogen (^{14}N). The *E.coli* cells grown on 'heavy' nitrogen were then transferred to a new medium containing only light nitrogen and allowed to divide once to produce a new generation. The DNA of these daughter cells was found to be halfway between the 'heavy' and 'light' values, indicating that half the DNA was old and half was new (semi-conservative replication).



The genetic code

The DNA base sequence forms a four letter language which, as you have seen, can be copied every time a cell divides. This DNA base sequence determines the sequence of amino acids in a polypeptide chain (the primary structure of proteins). A sequence of nucleotides and their bases which codes for one polypeptide is known as a gene. Each gene codes for a different polypeptide chain. The primary structure of a polypeptide is the basis of the particular structural shape and characteristic of the final protein, e.g. enzymes, structural materials and membrane proteins. The base code determines the structure, functions and individuality of every organism.

Remember that up to twenty different types of amino acids may occur in a single protein. The DNA code has a four letter base language (A, G, C, T). A triplet of bases (sequence of three in a row) codes for each amino acid, for example 'CGC' codes for the amino acid alanine (Ala) whilst 'GCT' codes for arginine (Arg), so the code 'CGC-GCT-CGC' would be translated as 'Ala-Arg-Ala' in a polypeptide. Note that the code is non-overlapping, i.e. it must be read 'CGC-GCT-CGC', not 'CGC-GCG-CGC-GCT-CTC-' etc.

Sixty four (4³) different triplet codes (codons) are possible with this four letter base language, more than sufficient to code for the twenty different types of amino acids. In fact most amino acids are coded for by more than one codon. As a result of this 'spare capacity' in the code, the code is referred to as a 'redundant' code. The process by which this code is used in protein synthesis, is described below.

Protein Synthesis

Protein synthesis involves all three of the RNA types described above working in combination, and is achieved in two stages. As the DNA cannot leave the nucleus, the code has to be read and copied (transcribed) into mRNA, in a process called **transcription**. The mRNA moves out of the nucleus and associates with the ribosomes, where the code (now embedded in the mRNA) is used in the synthesis of a polypeptide in the process of **translation**.

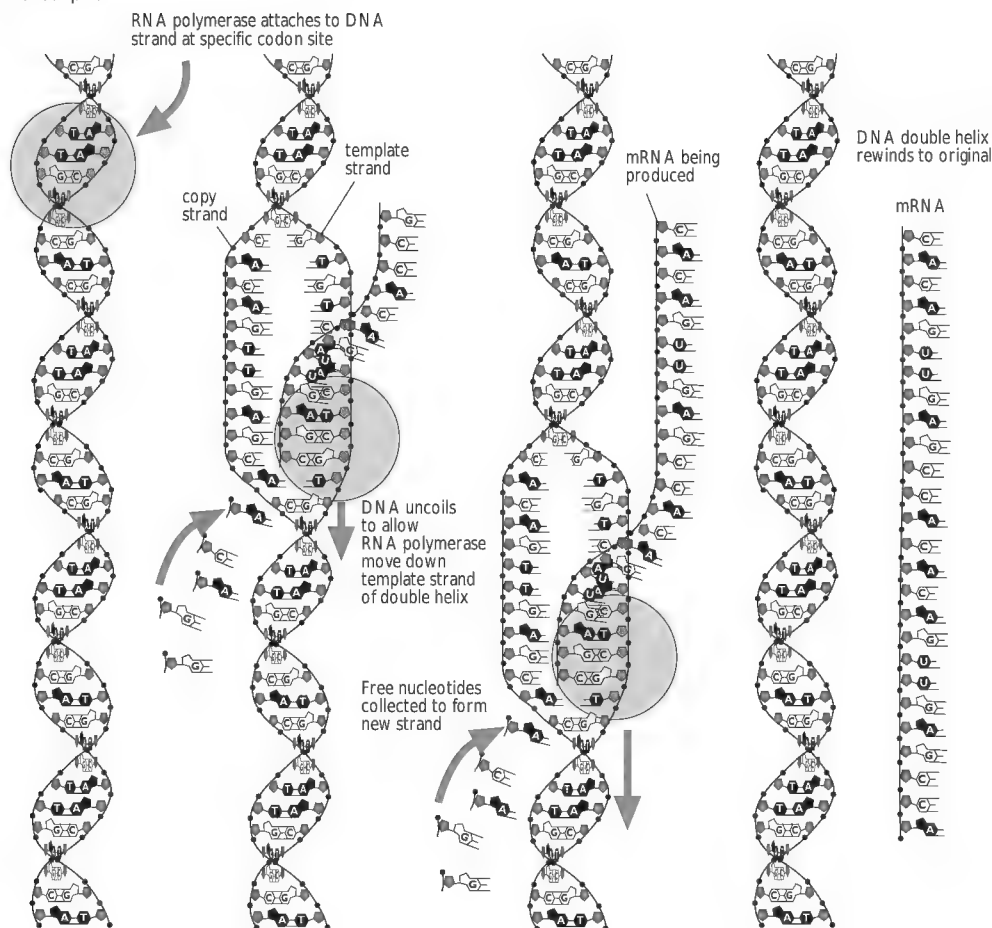
Transcription begins as an enzyme, **RNA polymerase**, attaches to the 'Start' codon of a gene. The DNA base sequence of this 'Start' codon is always 'TAC'. As RNA polymerase attaches to the DNA, the hydrogen bonds binding the two strands of the DNA double helix break apart to expose the sequence of triplet base codons on both strands. The enzyme then travels rapidly down the length of the gene like a zip fastener unzipping the DNA. As it does so, a molecule of mRNA is formed as a copy of one of the DNA strands. Only one of the two DNA strands is copied into mRNA, called the **template strand**. The mRNA is therefore an exact replica (save that 'U' is substituted for 'T') of the other strand, consequently referred to as the **copy strand**. When the enzyme reaches the 'Stop' codon of the gene, transcription ends, the enzyme is free to start the process again, and mRNA is released out through a pore in the nuclear membrane to the ribosomes where translation occurs.

A complicating feature of the process of transcription in eukaryotic cells (cells with a nucleus) is that the length of DNA (the gene) to be copied into mRNA, has sections of 'junk code' which do not code for any of the required amino acids in a polypeptide chain. The 'junk' sequences are called **introns** and the parts to be transcribed and translated are called **exons**. The whole length is transcribed into mRNA, but before it is released from the nucleus, the introns are cut out with the assistance of enzymes, leaving a single, 'unpolluted', strand.

◆ CHECKPOINT SUMMARY

- ◆ DNA and RNA are long chain polynucleotide molecules with repeating sub-units of mononucleotides combined as a result of condensation reactions.
- ◆ Mononucleotides consist of a 5 carbon sugar, a phosphate, and an organic base.
- ◆ In DNA the sugar is deoxyribose and the organic base can be one of adenine, thymine, cytosine and guanine.
- ◆ In RNA the sugar is ribose and the organic base can be one of adenine, uracil, cytosine and guanine.
- ◆ RNA is a single stranded helix with base pairs of adenine-uracil and cytosine-guanine.
- ◆ There are three types of RNA - messenger, transfer and ribosomal.
- ◆ The DNA molecule is a double stranded helix with the two strands held together by hydrogen bonds between complementary base pairs adenine-thymine and cytosine-guanine.
- ◆ DNA carries out semi-conservative replication in which each strand of the original molecule acts as a template for the construction of a new one, so that each new double stranded molecule of DNA consists of one original strand and a new complementary strand.
- ◆ The synthesis of new strands of DNA is catalysed by enzymes, including DNA polymerase.
- ◆ A gene is a length of DNA which carries the genetic information for the synthesis of a single polypeptide chain. The gene determines the primary structure of the polypeptide, that is the sequence of amino acids.

Transcription

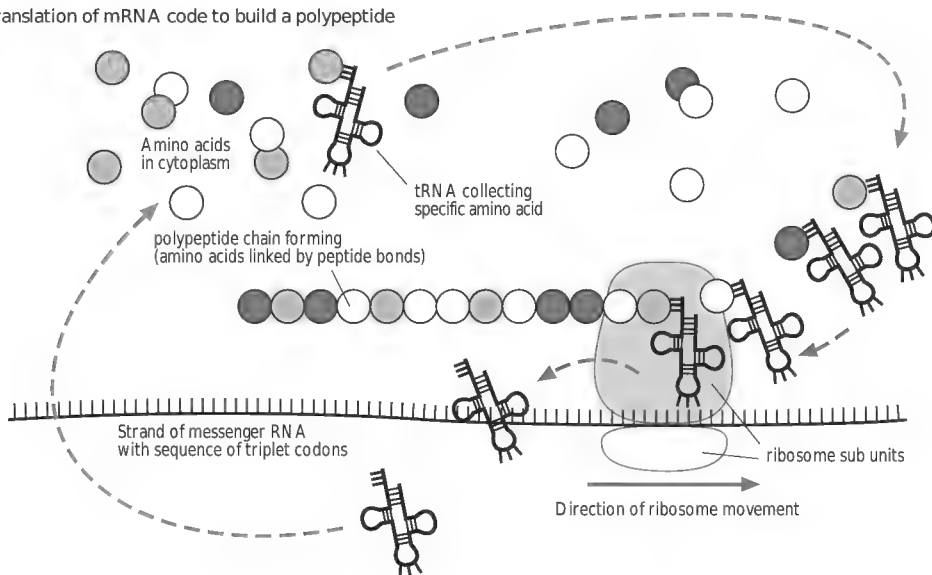


Translation occurs at ribosomes which are made up of two sub-units, one larger than the other, which come together only for the purpose of translating a length of mRNA. The mRNA binds to the small sub-unit at its 'Start' codon (AUG). It is then joined by the large sub-unit along with a molecule of tRNA which has the anti-codon 'UAC' and which carries the amino acid methionine. As the three different RNA types come together, the interface between the small and large sub-unit of the ribosome forms two binding sites allowing two triplet codons be lined up side by side. The process of translation can then proceed.

A second tRNA now occupies a position on the mRNA alongside the first and, as it does so, a peptide bond is formed between the two amino acids. The ribosome moves along the length of the mRNA, and once a tRNA molecule has delivered the appropriate amino acid it is released to repeat the process. New tRNA molecules with their amino acids come to occupy the ribosomal coding sites, and the polypeptide chain grows ever longer. When the ribosome reaches the 'Stop' codon (UAG) on the mRNA, it splits into its separate sub-units releasing the mRNA and the now complete polypeptide. A number of ribosomes move along the mRNA at the same time so that many polypeptide molecules are formed simultaneously. It is calculated that, in the average mammalian cell, more than a million new peptide bonds are being formed every second.

Generally mRNA molecules only have a short existence, sometimes just a few minutes, so that if continuous supplies of a particular protein is required the above processes must be repeated.

Translation of mRNA code to build a polypeptide



DNA control of enzyme synthesis

All enzymes are proteins, and are synthesised in the processes of transcription and translation in the same way as all proteins. The amount produced is regulated by any factors which influence these processes. These include the switching on and off of genes, and the length of life of the mRNA. Some enzymes are only produced (induced) in the presence of the substrate, and for this to be possible there must be some feedback signal from the cytoplasm of the cell which detects the presence of the substrate and results in the appropriate gene being switched on, for example lactase enzyme is produced in response to the presence of lactose.

The Human Genome Project

The 'genome' is the complete set of genetic information contained within a single cell. It is copied nearly exactly in every cell of the body. As you have seen, the DNA lengths which make up the individual genes contain 'junk' sequences called introns which are not translated into protein. In addition there are many repeating sequences of DNA lying between the genes which have no known role in protein synthesis. In fact 95% of the human genome is 'junk' DNA.

The Human Genome Project, which began in the mid 1980s, aimed to map and sequence all the nucleotides including those of the 'junk' sections. **'Mapping'** entails discovering the exact location of each gene on the different chromosomes: **'sequencing'** means determining the position of every letter of the base code on every length of DNA. The Human Genome Project has received worldwide cooperation and the first complete drafts emerged in early 2000. In all, there are about one billion codons in the human genome (3 billion nucleotides) and each chromosome contains about 4000 genes on its DNA.

You may be wondering why the scientific world should consider it so important to know these precise details. Different answers might be given by people working in different fields. For the academic geneticist, the genome is an autobiography of the human species. It contains genes acquired at every stage of the evolution of our species from the earliest prokaryotic life forms, and reveals patterns of inheritance which explain relationships so far undiscovered from the fossil record and other sources. For medicine it opens up a completely new horizon: the possibility of diagnosing the susceptibility of particular individuals to particular diseases, as the following example illustrates.

Huntington's chorea is a disease which results in degeneration of mental processes (dementia) and loss of motor control. The onset of this condition is characterised by uncontrolled, random flicking movements. It is inherited in a gene which is located on chromosome number 4. The gene normally contains the codon CAG repeated over and over, normally ten to fifteen times, but many more in people susceptible to the disease. The exact age at which Huntington's disease develops seems to depend upon the number of times this codon is repeated. 39 repetitions, for example gives a 90% chance of dementia by the age of 75, and 50 repetitions predicts the onset of dementia at the age of 27.

You might argue that knowing what the future holds in store is less than small comfort if there is no chance of prevention or cure but it

◆ CHECKPOINT SUMMARY

- ◆ The sequence of nucleotide bases on one strand of the DNA molecule carries the genetic code for the synthesis of proteins and hence ultimately living organisms.
- ◆ Three bases (a triplet codon) code for one amino acid.
- ◆ There are 64 (4^3) possible combinations of any three from four bases, but only 20 amino acids to be coded for.
- ◆ Amino acids are coded for by more than one triplet codon and the code is said to be 'redundant' or 'degenerate'.
- ◆ A gene is a sequence of nucleotide bases of a DNA molecule which codes for a polypeptide.
- ◆ A gene for a polypeptide has a specific 'start' codon which thus sets the order of all the subsequent triplet codons.
- ◆ Thus the code is non-overlapping i.e. a base can only be 'used' in one triplet codon.
- ◆ Only a fraction of the nuclear DNA contains genes coding for proteins, the rest consists of so-called 'junk' DNA the function of which is not understood.
- ◆ Nuclear DNA with the genetic code never leaves the nucleus in eukaryotic cells.
- ◆ The genetic code (a gene) for a polypeptide is copied (transcribed) into mRNA which leaves the nucleus and associates with the ribosomes.
- ◆ The ribosomes 'read' the genetic message on the mRNA, and tRNA delivers amino acids in the sequence determined by the code.
- ◆ There are 20 different types of tRNA, each specific to a particular amino acid.
- ◆ Each tRNA has a specific binding site at which the specific amino acid combines and an anti-codon which matches the specific codon for that particular amino acid.
- ◆ The amino acids combine by means of peptide bonds to give a polypeptide chain.
- ◆ The polypeptides subsequently form proteins.
- ◆ As enzymes are proteins their synthesis is controlled by DNA.

Spiritually, morally and ethically the debate includes the consideration of emergent properties, that is how much more we are than simply the sum of our parts. Mapping and sequencing are analytical approaches, and do not address the problem of the human condition in its entirety in the context of the ever changing environment.

1.2

Enzymes

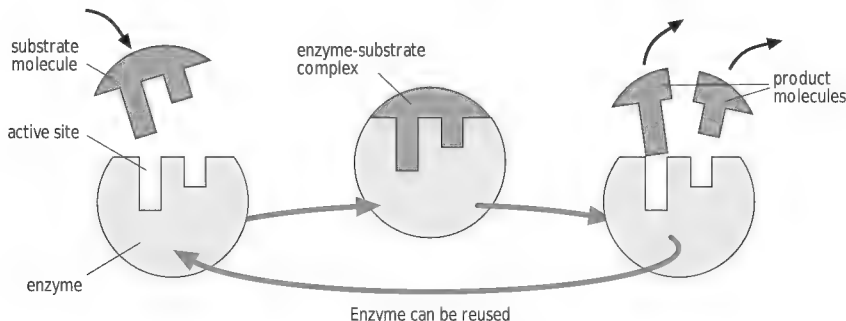
Content

- ▼ The structure of enzymes as globular proteins, and the concept of the active site and specificity
- ▼ Enzymes as catalysts which reduce activation energy
- ▼ The effects of temperature, pH, substrate and enzyme concentrations on enzyme activity
- ▼ Active site-directed and non-active site-directed inhibition of enzyme action
- ▼ The commercial uses of enzymes as illustrated by pectinases in food modification and proteases in biological detergents
- ▼ The advantages of the immobilisation of commercial enzymes, as illustrated by lactase
- ▼ (Practical work to include experiments to investigate the effects of temperature, pH and enzyme concentration on enzyme activity using suitable enzymes, illustrations of enzyme immobilisation using lactase, the use of pectinase in the production of fruit juice)

Introduction

Most students of science can name an enzyme. Usually it is a digestive enzyme like amylase or pepsin, but enzymes are not just concerned with breakdown reactions like digestion, they can also help build things up. In fact, every chemical reaction in every living cell is made possible by an enzyme. Several thousand enzymes have been isolated and studied.

Enzymes are protein molecules. Compared to many other molecules they are relatively large (macromolecules) of the globular type with a complex tertiary structure. What gives each enzyme its particular qualities and mode of action is the way in which its peptide chains are folded and twisted into specific shapes. As you will see in the following account, enzyme action depends upon shape recognition between enzymes and other reacting molecules called **substrates**.

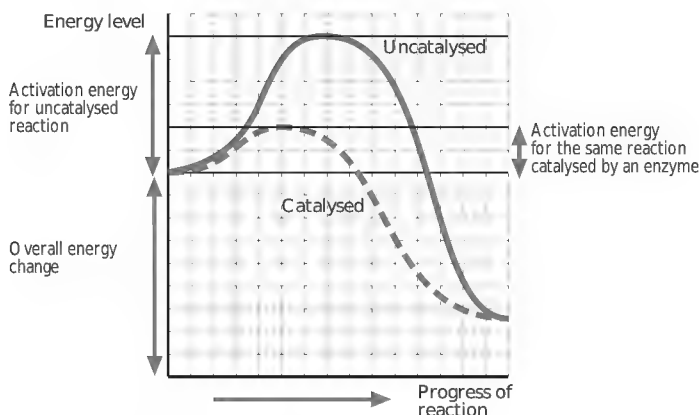


Enzymes as catalysts

Enzymes are **biological catalysts**. A catalyst is a substance which speeds up a reaction without being changed itself in the process. As they are not used up or changed, enzymes can be used repeatedly; therefore they are effective in relatively small amounts.

Usually enzyme molecules are much larger than the reacting molecules (substrates). In an enzyme-catalysed reaction, the substrate(s) become attached to a particular region on the enzyme called the **active site** which has a specific shape and structure matching that of the substrate(s), forming the **enzyme - substrate complex**. This association is temporary and lasts only long enough to allow the substrate molecules to interact to form the products. Once the products are formed, they are released from the active site and the enzyme is free to repeat the process.

The formation of the enzyme-substrate complex lowers the **activation energy** which is the energy needed to start a reaction. In the laboratory, it is common for reacting substances (substrates) to be heated in order to make the reaction occur more quickly. The heat energy causes the molecules to move about more rapidly (i.e. it gives them more kinetic energy) so that they collide more frequently, forming the product. In other words heat is used to overcome the activation energy. Living cells operate at a constant, relatively low temperature so therefore they rely on enzyme catalysts to overcome the activation energy.



The active site matches the substrate, so different shaped substrate molecules require different shaped active sites. Most biological reactions therefore involve different **specific** enzymes. This is possible because proteins which make up enzymes can be made in an infinite variety of shapes as a result of the nature and sequence of the amino acids and their R groups.

This model of enzyme action is referred to as the **lock and key model**, but it is known that the shape of the active site may change as the substrate makes contact with it, adjusting to make a close fit, rather like a soft glove around a hand, a mode of action called **induced fit**.

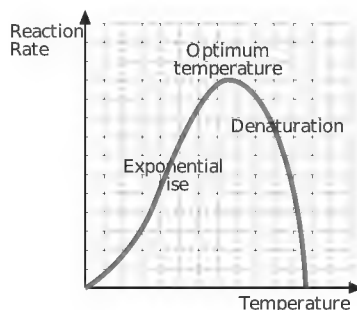
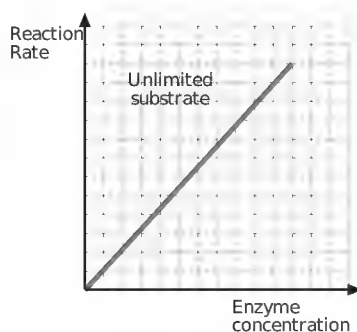
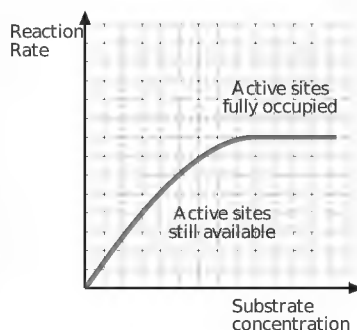
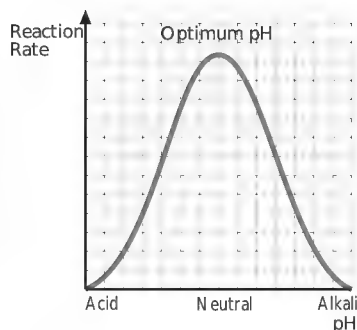
The effects of temperature, pH, substrate and enzyme concentration on enzyme activity

pH is a measure of H^+ ion concentration, which is a measure of acidity and alkalinity. A pH of 7 is neutral, less than 7 is acid, and more than 7 is alkaline. Small changes in pH can affect the association process between enzyme and substrate which happens at the active site. The attraction between substrate and enzyme is often the result of small electric charges at the active site, and these are disrupted by changes in H^+ ion concentration. Extremes of pH, i.e. very acid or alkaline conditions, cause permanent denaturation. Enzymes have an optimum pH for efficient functioning. Usually this is around pH7, the normal pH of cells. Notable exceptions are the enzyme pepsin, which is found in the stomach and works best in highly acidic conditions in the range pH 1-2, and the enzyme trypsin which is found in the duodenum and has an optimum pH of 9.

Temperature affects the rate of all chemical reactions. As the temperature increases, so does the kinetic energy of the reacting molecules. More enzyme/substrate complexes are formed as the reactants collide more frequently, and the reaction rate rises exponentially, doubling for every $10^\circ C$ rise in temperature. However, enzymes, like all proteins, suffer irreversible alterations in molecular shape above certain temperatures as a result of the breaking of chemical bonds within the molecule, so that in enzyme-catalysed reactions, there is an **optimum** temperature above which the reaction rate drops sharply. For an enzyme, any change in the shape of the active site means a loss of function, the enzyme is said to be **denatured**. For most enzymes, the optimum temperature is around $40^\circ C$, but there are exceptions. For example, some bacteria living in hot springs have enzymes which function at temperatures above $85^\circ C$, whilst the ice fish of the Antarctic possess enzymes which operate at $-2^\circ C$.

Enzyme Concentration exerts a direct effect on the rate of the reaction as long as there is a plentiful supply of substrate. Any increase in the number of enzyme molecules will result in a proportional increase in the number of enzyme-substrate complexes and therefore an increase in the rate of reaction.

Substrate concentration has a similar effect. At low substrate concentrations, not all the active sites of the enzyme molecules will be occupied, so the rate of the reaction depends upon the concentration of substrate alone. As the concentration of substrate increases, so all of the available active sites will become filled. The upper limit is determined by the amount of enzyme molecules available.



Enzyme Inhibitors

Enzyme inhibitors are substances which interfere with the active site of the enzyme.

Active site-directed inhibitors block the actual active site directly.

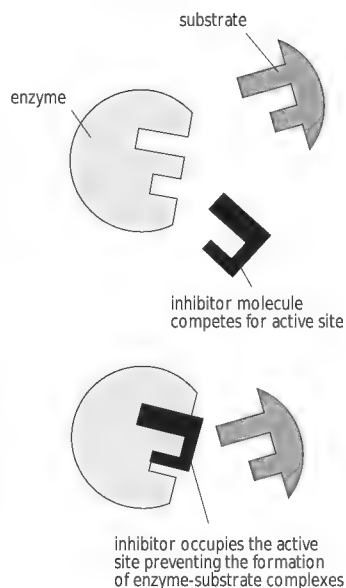
Non-active site-directed inhibitors attach a part of the enzyme away from the active site, but alter the enzyme's molecular shape so that the enzyme-substrate complex cannot be formed.

Competitive inhibitors are active site-directed substances which have a molecular structure resembling that of the substrate. They attach themselves to the active sites forming inhibitor/enzyme complexes and cause the reaction to slow down or stop altogether. The effect of competitive inhibitors depends upon the relative concentrations of the substrate and inhibitor, and also the relative stability of the enzyme/substrate and inhibitor/enzyme complexes. This type of inhibition is seen in the action of a group of antibiotics called sulphonamides, which compete for the active site of a key bacterial enzyme involved in synthesising an essential growth factor, not found in the cells of the host.

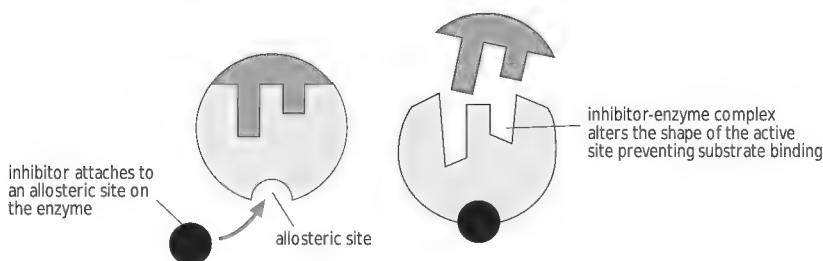
Non-competitive inhibitors are non-active site-directed and are substances which bind onto the enzyme at a place other than the active site called an **allosteric site**, causing the enzyme to change shape sufficiently to stop enzyme-substrate complexes being formed. Non-competitive inhibitors are not similar to the substrate molecules and are not affected by the substrate concentration. The ions of some heavy metals such as arsenic and cyanide may bind onto allosteric sites and act as poisons, stopping important enzyme controlled reactions. (Some enzyme molecules possess an allosteric site which must be occupied by an **activator** substance to give the enzyme its correct working shape. Without the activator, the enzyme will not work.)

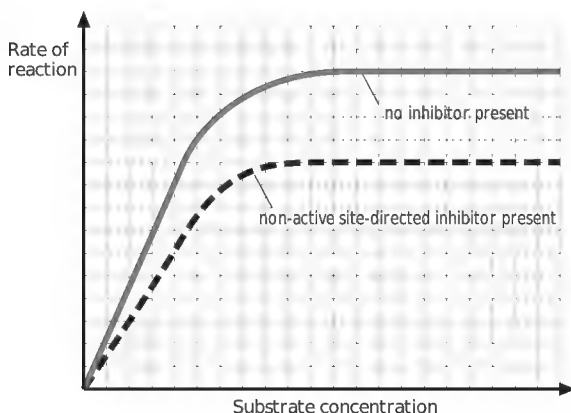
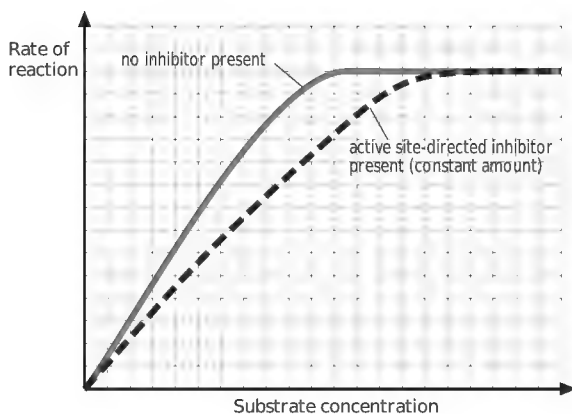
Inhibitors and activators are important in regulating the activity of enzymes in the complex metabolic pathways of the body.

Active site-directed



Non-active site-directed





CHECKPOINT SUMMARY

- ◆ All enzymes are protein in nature, and fall into the group of 'globular' proteins with a complex 3D structure
- ◆ Enzymes are catalysts which speed up the rate of reaction of much larger amounts of reactants without themselves being used up in the process
- ◆ Unique amongst catalysts they are denatured by extreme conditions of pH and temperature etc.
- ◆ Their activity depends upon their complex 3D shape which creates an active site which combines with the substrate to form an enzyme/substrate complex which lowers the activation energy of reactants
- ◆ Their complex 3D shape also accounts for enzyme specificity as the active site has a shape complementary to the shape of the substrate
- ◆ Disruption of the 3D shape accounts for denaturation
- ◆ pH has an effect on the 3D shape of enzymes, especially the active site which has an electric charge
- ◆ Any effect on the active site alters the reactivity of the enzyme. There is an optimum pH, either side of which reactivity drops
- ◆ Extremes of pH permanently disrupt the active site and thus denature the enzyme
- ◆ Similar effects are seen with temperature, except low temperatures do not denature enzymes. The rate of enzyme catalysed reactions, like all chemical reactions, are reduced with low temperatures
- ◆ Optimum conditions of pH and temperature vary with the particular enzyme, which reflects the conditions in which the cell exists
- ◆ The relative amounts of enzyme and substrate affect the rate of reaction as it affects the formation of the enzyme substrate complex. Only one can be rate regulating or limiting at any one time
- ◆ Active site-directed inhibition interferes with the active site so that combination with the substrate is prevented, e.g. competitive inhibition when a substance with a shape similar to the substrate occupies the active site
- ◆ Non-active site-directed inhibition involves combination of a substance (often an end product) with an allosteric site, which alters the overall shape of the enzyme, and thus the active site.

The commercial use of enzymes

Although enzymes have only been investigated scientifically for just over a century, they have been used for by humans for thousands of years: they are, for example, essential in brewing (the name enzyme meaning “in yeast”), the production of cheeses, and the practice of hanging meat before eating it is based on the tenderising action of protease enzymes. While we are still far from identifying and understanding the range of enzymes and enzyme functions in living cells, knowledge of some enzyme catalysed reactions has led to the development of enzyme-based technology. A range of enzymes now have important commercial applications in industries including the food and drink industry, the paper industry, and the pharmaceuticals industry. For a range of financial and biological reasons most of the enzymes used in these industries are obtained from fungi and bacteria.

Since it has become possible to extract pure enzymes from cultures of bacteria and fungi on a commercial scale, they have been put to use in many different ways.

Biological Washing Powder is one which contains digestive enzymes in addition to the normal detergent. Protein digesting enzymes (**proteases**) help break down protein stains like egg and blood. Fat digesting enzymes (**lipases**) deal with grease, whilst starch digesting enzymes (**amylases**) work on starch based food products such as gravy. The broken down products of these ‘biological stains’ are then easily washed out.

Washing powder manufacturers invest heavily in the development of new, genetically designed, enzymes which can operate at the temperatures and pH levels of the average washing machine. Although some early forms used enzymes that could only resist temperatures of 40°C, newer products can be used in washes at 60°C or above with improved results. Fabric Softener may contain the cellulose digesting enzyme **cellulase**. It is present in concentrations just sufficient to erode the tiny cellulose fibres on the surface of cotton garments, making them feel softer and smoother.

The extraction of fruit juice involves the release of the juice of a fruit from within the sap vacuoles of its cells. In order to extract it more efficiently, two types of enzyme are added before the fruit is crushed. One is cellulase, which weakens the cellulose cell walls. The other is **pectinase**, an enzyme which attacks the glue-like substance **pectin** which forms the middle lamella, sticking cells together. Mixtures of the enzymes are available commercially from a fungal source (*Aspergillus niger*). In the preparation of citrus fruit juices (orange, lemon, lime and grapefruit), the fruit skins are subjected to abrasion first so that the enzymes can penetrate the fruit tissues, then after soaking in the enzyme mixture (usually at around 35°C) for a few hours, the peel and pith can be easily separated from the juice containing tissues. The resulting yield of juice is greater and purer than from the traditional practice of crushing the fruit whole, then separating the solid matter.

Immobilisation of commercial enzymes

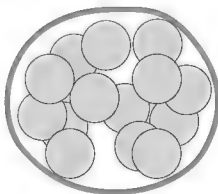
Since enzymes, like all catalysts, do not get used up in the processes they catalyse, they can be reused again and again. This is particularly desirable since enzymes are expensive to produce. One of the difficulties of reusing enzyme is, however, the difficulty of recovering the enzyme from the substrate where it is in a very low concentration. This can be a time consuming and expensive exercise. If the enzyme is not recovered then not only is the process wasteful, but may also be harmful as the final product will be contaminated with enzyme.

For these reasons the development of immobilised enzymes has improved enzyme technology enormously. Immobilised enzymes are enzymes that have been attached to another (insoluble) material in some way and hence prevented from moving freely within the substrate mixture. They may be attached to a fixed membrane or gel made of a range of substances including silica, starch, or cellulose. In other cases the enzyme may move within the substrate but only once encapsulated within beads of another material. In the former systems enzymes never become mixed with the product whereas encapsulated enzymes are mixed in with the final product but are easily extracted by filtering or other methods.

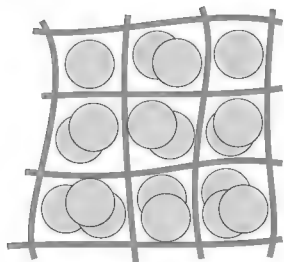
Absorption



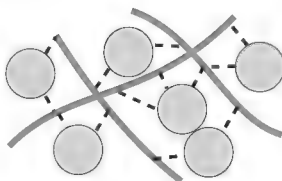
Encapsulation



Entrapment



Covalent bonding



There are many advantages to immobilising enzymes in addition to cost and ease of extracting a pure product.

- ▼ Immobilised enzymes may be more easily added to and removed from reactors to allow the rate of reaction to be more carefully controlled. This means that enzymes can be used to partially but not completely digest a substrate.
- ▼ Immobilised enzymes can lead to much greater production efficiency. They can be used in a continuous enzyme reactor where substrates are constantly added and products constantly produced without the need to add or extract enzyme.
- ▼ Immobilised enzymes tend to be more stable (better able to resist alteration to shape and activity.) In particular they are less likely to be inactivated or denatured by changes in pH, presence of other chemicals, or high temperatures (they are more thermostable).
- ▼ Immobilised enzymes can also be used for longer before their activity decreases and are less likely to lose activity during periods of storage.

A disadvantage of immobilising enzymes is that the rate of reaction may be slower because the enzyme has reduced kinetic energy and is often partitioned from the substrate by a membrane through which the substrate must diffuse.

Use of immobilised lactase to produce lactose-reduced milk

Lactose (milk sugar) is a disaccharide made up of two hexose sugars (glucose and galactose). It is essential to the diet of infants, but adults may develop 'intolerance' to lactose which means that they are unable to digest it and it remains unaltered in the intestine. This, in itself, is not a problem but undigested lactose may be acted on by bacteria to produce lactic acid (lactate) which can cause abdominal pain and diarrhoea.

Lactose containing milk can be converted to lactose-reduced milk by trickling it over a column of alginate beads containing immobilised lactase enzyme. By testing the milk outflow at the bottom of the column for the presence and relative quantity of monosaccharide products (glucose and galactose), the flow rate can be adjusted to its optimum efficiency.

◆ CHECKPOINT SUMMARY

- ◆ *Enzymes have many commercial uses as a result of their catalytic properties and specificity, e.g. pectinases in food modification and proteases in biological detergents*
- ◆ *The extraction of fruit juices aided by addition of enzymes; cellulase which weakens cellulose cell walls, and pectinase which attacks glue-like substance pectin which forms middle lamella, sticking cells together*
- ◆ *The resulting yield of juice is greater and purer than from the traditional practice of crushing the fruit whole, then separating the solid matter*
- ◆ *A biological washing powder is one which contains digestive enzymes in addition to the normal detergent*
- ◆ *Protein digesting enzymes (proteases) help break down protein stains like egg and blood. Fat digesting enzymes (lipases) deal with grease, whilst starch digesting enzymes (amylases) work on starch based food products such as gravy. The broken down products of these 'biological stains' are then easily washed out*
- ◆ *Newer products with thermostable enzymes can be used in washes at 60°C or above with improved results*
- ◆ *Immobilisation of commercial enzymes enables them to be reused again and again, and prevents them being lost to contaminate the end product*
- ◆ *Immobilised enzymes are enzymes that have been attached to another (insoluble) material in some way and hence prevented from moving freely within the substrate mixture*
- ◆ *They may be attached to a fixed membrane or gel made of a range of substances including silica, starch, cellulose. In other cases the enzyme is encapsulated within beads of another material and mixed within the substrate, and are recovered by filtering or other methods*
- ◆ *Immobilised enzymes can lead to much greater production efficiency with continuous flow of reactants past the immobilised enzyme*
- ◆ *Immobilised enzymes tend to be more stable and are less likely to be inactivated or denatured by high temperatures, changes in pH, or presence of other chemicals*
- ◆ *Immobilised enzymes can also be used for longer before their activity decreases*
- ◆ *A disadvantage of immobilising enzymes is that the rate of reaction may be slower because the enzyme has reduced kinetic energy and is often partitioned from the substrate by a membrane through which the substrate must diffuse*
- ◆ *An example is immobilised lactase used to produce lactose reduced milk.*

1.3

Cellular Organisation

Content:

Prokaryotic cells

- ▼ The structure of a bacterial cell and its inclusions as illustrated by *Escherichia coli*.
- ▼ The roles of the cell wall, cell surface (plasma) membrane and its invaginations, flagella, bacterial chromosomes, plasmids, glycogen granules and lipid droplets.

Eukaryotic cells

- ▼ The organisation of eukaryotic cells as illustrated by a leaf palisade cell and a liver cell.
- ▼ Light and electron microscopy compared (magnification and resolution)
- ▼ The structure and roles of the nucleus, nucleolus, rough and smooth endoplasmic reticulum, Golgi apparatus, lysosomes, chloroplasts, mitochondria, ribosomes, centrioles and microtubules, the cellulose cell wall.
- ▼ The structure, properties and roles of the cell surface (plasma) membrane.

Transport across membranes

- ▼ How molecules and ions move into and out of cells.
- ▼ The principles involved in passive transport by diffusion and facilitated diffusion.
- ▼ The principles of osmosis in terms of the diffusion of water molecules from a higher to a lower water potential through a partially permeable membrane.
- ▼ The factors which affect water potential
- ▼ The principles involved in active transport; endocytosis and exocytosis.

Aggregations of cells

- ▼ Tissues as aggregations of cells of common origin, structure and function, as illustrated by the tissues of a mesophytic leaf.

Introduction

All living organisms are composed of cells. It is calculated that an average human adult is made up of around 10^{14} cells, each coordinated with the others to form functional tissues, organs and systems. At the other extreme, some organisms are composed of a single cell; Amoeba, bacteria and yeast are examples of single celled organisms.

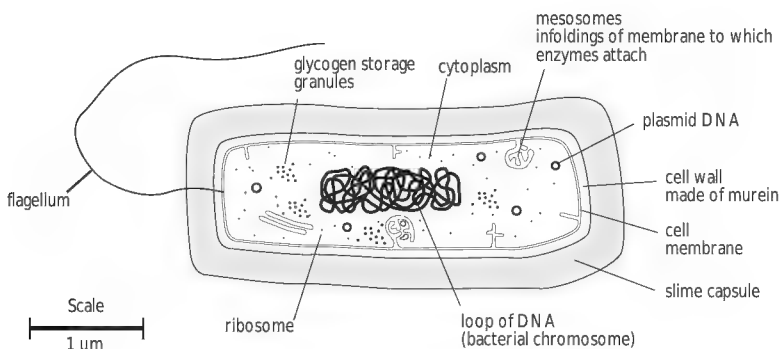
Cells are grouped into two major types, **prokaryotic** and **eukaryotic**, the most important distinction between them being the presence or absence of a nucleus ('*karyon*' in Greek means 'nucleus', '*eu*' means true, and '*pro*' means 'before'). Eukaryotic cells are so named because they have a true nucleus and prokaryotic cells are built on an earlier design without a true nucleus.

PROKARYOTIC CELLS

Prokaryotes are all single celled organisms and they are classified in a separate kingdom called **Kingdom Prokaryotae**, and include the bacteria. Prokaryotic cells are much smaller than eukaryotic cells, ranging from 1-10 μm in size (eukaryotic cells range from 10-100 μm). Although bacteria are all constructed according to the same basic pattern, they are a very diverse group with individual types capable of inhabiting parts of the earth as distinct from each other as hot sulphurous springs to permafrost, some are photosynthetic, others (decomposers) live off the dead remains of other organisms, assisting in the breakdown, decay and recycling of essential nutrients. A few have gained notoriety as disease agents (pathogens) due to their parasitic life style e.g. *Mycobacterium tuberculosis* (TB), *Salmonella enteritidis* (food poisoning).

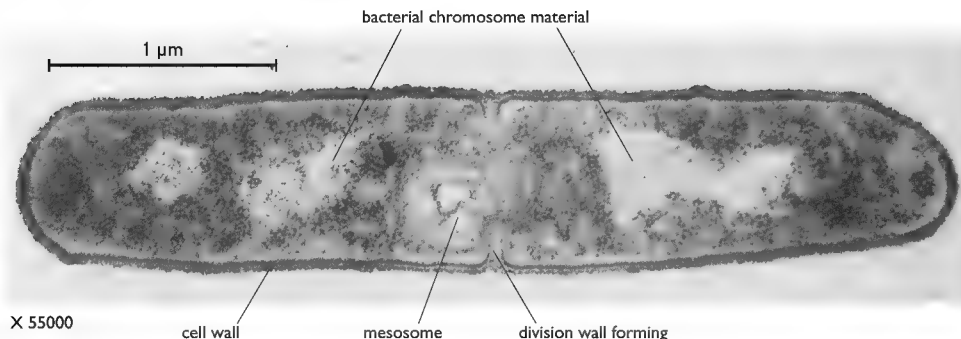
Not all bacteria are able to move, but some possess **flagella**, capable of propelling the organism through water. The cell wall is not made of cellulose, but is formed from a mixture of polysaccharides and amino acids called **murein**. Many bacteria which cause disease (pathogenic bacteria) have a **slime capsule** as their outermost layer which helps in protection against the body defences of the infected organism.

Bacteria generally divide and reproduce themselves much quicker than eukaryotes. Each bacterium divides into two (binary fission) to give two new daughter cells. Growth of bacterial populations can show a doubling every 20 minutes or so in ideal conditions.



Escherichia coli (*E. coli*) is a bacterium common in the gut of humans and other animals, it can occasionally however cause disease. *E. coli* has flagellae all over its surface. Like other Prokaryotic cells, it does not possess **organelles** (organelles are membrane bound structures found in Eukaryotic cells, e.g. nucleus, mitochondria, chloroplasts.) Its outer membrane folds inwards, however, to form special areas (**mesosomes**) for the attachment of enzymes. The DNA is not enclosed by a nuclear membrane but exists as a single main coil, **E**

EM of a section through a dividing rod-shaped bacterium



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with smaller loops of DNA (**plasmids**) containing just a few genes, scattered in the cytoplasm. Food energy reserves are stored in glycogen granules and fat droplets.

Due to their small size, the detail described above can only be seen under the electron microscope. Under the typical laboratory light microscope bacteria will be seen as tiny darkly staining specks, even at the highest magnification.

EUKARYOTIC CELLS

Eukaryotic cells (all cells other than the prokaryotic cells) do possess a membrane bound nucleus, within which is to be found DNA and histone proteins which form into chromosomes just before nuclear and cell division. Eukaryotic cells also possess membrane bound organelles; e.g. mitochondria, endoplasmic reticulum, Golgi apparatus, lysosomes, and if photosynthetic - chloroplasts. The occurrence and distribution of these organelles depends upon the type of eukaryotic cell that is under consideration. Like prokaryotic cells they all possess ribosomes. The description of a 'typical' eukaryotic cell is not possible, due to the wide range of structure and function. However, the two groups (plant and animal cells) can be illustrated by reference to plant leaf palisade cells and animal (mammalian) liver cells.

◆ CHECKPOINT SUMMARY

- ◆ Prokaryotic cells (bacteria) lack a true nucleus and membrane bound organelles
- ◆ *Escherichia coli* (*E. coli*) is a bacterium found in the large intestine of animals, normally it is harmless but can cause disease under certain circumstances; new mutations can be fatal.
- ◆ The DNA is located in a central strand (bacterial chromosome), and as circular plasmids in the rest of the cytoplasm
- ◆ The plasmids can be exchanged between bacteria, a fact exploited by genetic engineering
- ◆ The cell wall is not cellulose as in plant cells, but is formed from a mixture of polysaccharides and amino acids called murein
- ◆ The cell surface (plasma) membrane is partially permeable and controls the transport of substances into and out of the cell
- ◆ The cell wall provides protection and support, preventing bursting (lysis) of the cell in more dilute solutions
- ◆ Many disease causing (pathogenic) bacteria have a slime capsule covering the cell wall which helps in protection against the body defences of the infected organism
- ◆ Respiration is located in mesosomes which are infoldings of the cell surface membrane, sharing the principle of increased surface area of membranes with true mitochondria
- ◆ Ribosomes are present in both prokaryotes and eukaryotes
- ◆ Glycogen granules and lipid droplets act as energy stores
- ◆ Flagella provide bacteria with mobility.

Plant and animal cells as seen under the light microscope

Plant cells are generally easier to see under the microscope, as the cell membrane of each cell is surrounded by a relatively thick **cellulose cell wall** which gives each cell a more visible boundary.

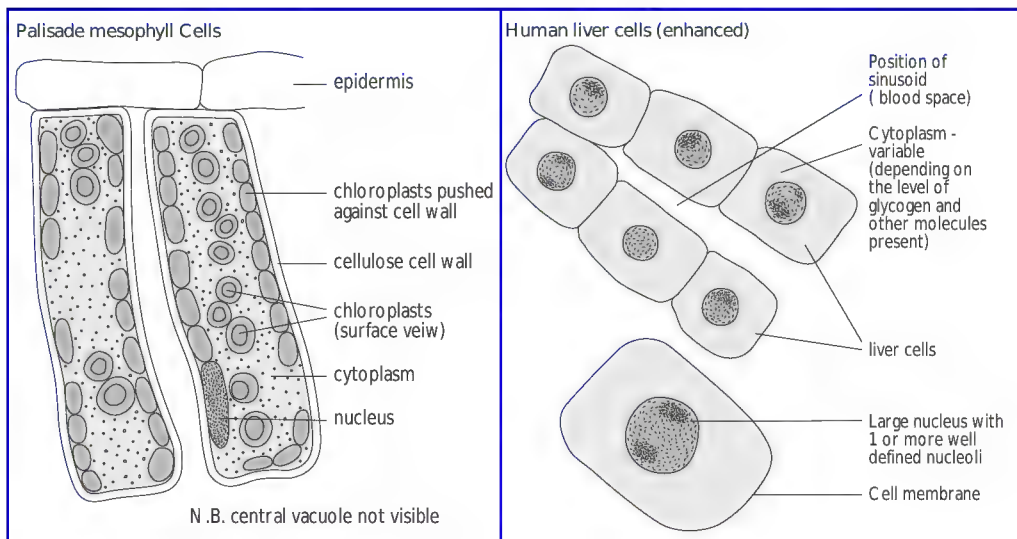
Leaf **palisade cells** are located just beneath the upper epidermis of the leaf and are specialised for the purpose of photosynthesis. Under the light microscope several typical plant cell structures can be seen in suitably stained specimens. They have a cellulose cell wall surrounding their cell surface membrane (plasmalemma), a large central vacuole surrounded by the tonoplast membrane, numerous chloroplasts which are aligned along the elongated vertical walls in such a way as to absorb the maximum amount of light. If living cells are observed it is possible to see the chloroplasts move within the cytoplasm to positions favouring optimum light utilisation.

Liver cells shows typical animal cell features. There are three obvious differences from plant cells which can be seen with a light microscope: the liver cell does not have a cellulose cell wall; the liver cell has many tiny scattered 'vacuoles' (more properly termed vesicles); they lack chloroplasts. Very little detail of the structure of liver cells can be seen under the typical laboratory light microscope, in fact only the darkly staining nucleus and paler staining cytoplasm and cell surface membrane.

To observe more of the structure of these cells the greater resolving power (resolution) and magnification of the electron microscope is required.

◆ CHECKPOINT SUMMARY

- ◆ *Eukaryotes do have a true membrane bound nucleus containing chromosomes of DNA and histone proteins, and membrane bound organelles as described previously*
- ◆ *Eukaryotic cells typically form tissues in multicellular organisms*
- ◆ *Cell differentiation and specialisation prevent the easy definition of typical animal and plant cells*
- ◆ *'Typical' cells would be those considered to show features common to the vast majority of cells in plants or animals*
- ◆ *A mesophyll cell from a leaf could be considered as a 'typical' plant cell*
- ◆ *A liver cell from a mammal could be considered as a 'typical' animal cell*
- ◆ *Under the best light microscope both the typical animal cell and the typical plant cell can be seen to possess a cell surface membrane, cytoplasm, nucleus with nucleolus, mitochondria, endoplasmic reticulum, and Golgi body*
- ◆ *In addition the typical plant cell can be seen to possess a cell wall around the cell surface membrane, a large central vacuole surrounded by the tonoplast membrane, and chloroplasts.*



Light microscopes and electron microscopes

Magnification

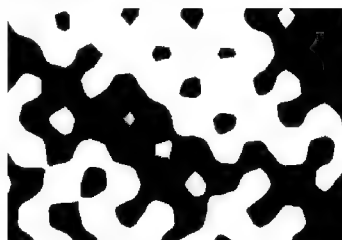
For the visual study of cell structure it is necessary to enlarge (magnify) them by the use of microscopes. Light microscopes that you are most likely to come across in general Biology laboratories usually magnify up to 400 times (special techniques could take this up to 1000 times). However, to continue magnifying objects past a certain point reveals no further detail. In order to see more detail it is necessary to increase the resolving power (resolution).



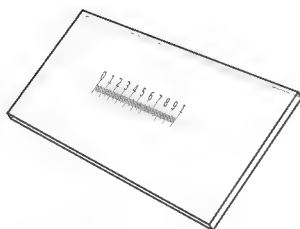
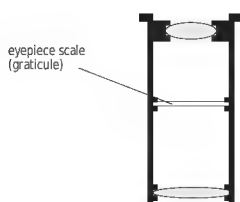
Resolution

Resolution or resolving power can be defined as the ability of a system (e.g. microscope, the eye) to distinguish (resolve) detail in an object. The amount of detail of a specimen that can be seen is determined by the resolving power of the microscope system being used. In the case of looking at material under the light microscope, the resolving power depends upon the light being able to distinguish this detail, which is determined by the wavelength of light. To resolve the detail, light must be reflected back from the structures. Any structures less than 0.2 micrometres (μm), that is 200 nanometres (nm) in diameter cannot be distinguished by light, nor can two structures closer than 0.2 μm be seen as separate.

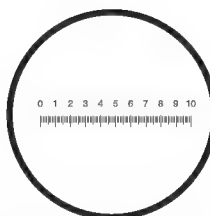
(1 μm = one thousandth of a millimetre, 1 nm = one millionth of a millimetre)



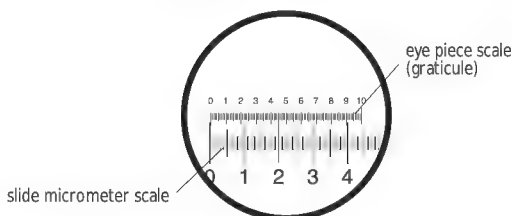
Measurement under a light microscope using an eyepiece graticule and slide (stage) micrometer



Scale in mm etched upon a microscope slide or a printed acetate sheet (slide micrometer)



Eyepiece scale as seen when held up to the light away from the microscope.



Accurate measurements can be achieved using the two scales in combination through the lenses of the microscope.

To improve the resolution, it is necessary to use a device which uses a beam of electrons, instead of light, called the **electron microscope**. Electron beams have a much shorter wavelength than light and give a hundred times better resolution. The magnification of an electron microscope picture (electron micrograph) can also be increased significantly to reveal this extra detail. The most powerful electron microscope can magnify up to $\times 500\,000$.

There are two types of electron microscope. In the **transmission electron microscope (TEM)**, an extremely thin section of the specimen is held on a copper or nickel grid and an electron beam passes right through it. Inside the electron microscope tube, electrons are accelerated by high voltage and focussed into a fine beam by a strong electromagnet (condenser lens). The beam passes through the specimen and is focussed further by additional electromagnets to give an image on a fluorescent screen, similar to the screen of a television set.

Electrons are disrupted by particles in the specimen to produce lighter and darker areas on the screen according to the relative density of those parts. If a photographic film plate is substituted for the fluorescent screen, the resulting picture is called an **electron micrograph**. A vacuum is maintained inside the tube of the electron microscope so that the electron beam is not scattered by molecules of the air e.g. oxygen and water. For this reason, it is impossible to view living specimens. Interpreting electron microscope images is difficult as they show the structure of dead cells which have been subjected to extreme mechanical and chemical trauma in the preparation process and are held in a vacuum.

Specimens are prepared by immersion in a series of increasingly pure solutions of alcohol which serve to dehydrate the cell components, then they are typically embedded in a block of resin which is cut into very thin sections by a machine resembling a high tech. bacon slicer called a microtome with a diamond or glass cutting surface. As the difference in density is not pronounced between one structure and another, it is common to 'stain' the specimen with the salts of heavy metals such as lead and uranium which increase the scattering of the electrons where the 'stains' are taken up and improve the contrast.

In the **scanning electron microscope (SEM)**, the beam of electrons passes back and forth across the surface of the prepared specimen producing a three dimensional effect. This technique is used to show surface features.

Remember that as light is not involved there is no colour in electronmicrographs, although they are often coloured 'artificially'.

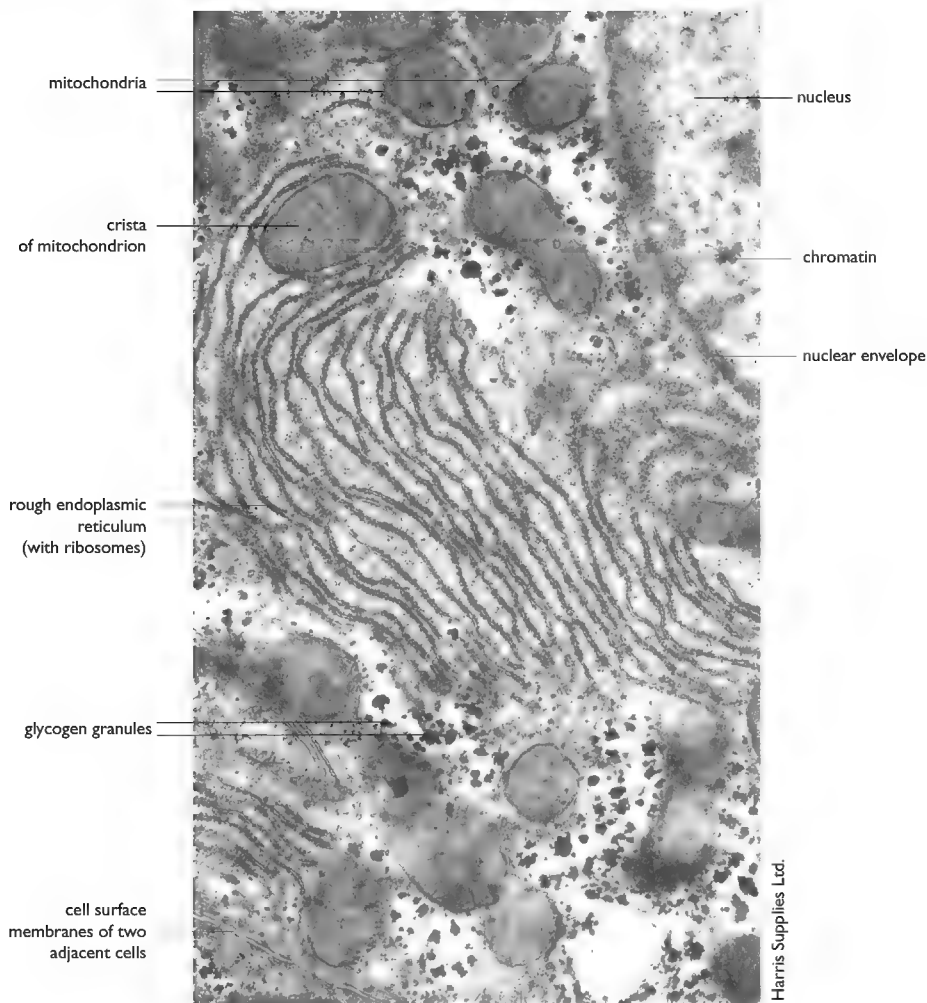
◆ CHECKPOINT SUMMARY

- ◆ *If the specimen can be observed with the naked eye without the need for magnification the calculation of the linear magnification of any drawing of it is straightforward - being the number of times any linear dimension of the drawing is greater than that of the specimen*
- ◆ *Magnifications of images of slides of biological material are given in terms of the magnification of the microscope image, that is by multiplying the power of the two lenses.e.g. $10 \times 10 = 100$*
- ◆ *However reproductions of the image as seen down a microscope introduce another layer of magnification which is often overlooked*
- ◆ *To calculate the linear magnification of drawings of microscope images of specimens it is necessary to know how many times the drawing is larger than the actual specimen*
- ◆ *The actual size of the specimen is measured with an eye piece graticule and stage micrometer*
- ◆ *Resolution is the ability to see detail*
- ◆ *The higher the resolution the more of the detail present can be seen*
- ◆ *Increasing magnification only reveals extra detail if the detail can be resolved*
- ◆ *Resolving power of light microscope limited by the wavelength of light*
- ◆ *Put simply some detail is so small that it cannot be 'hit' by light, and therefore cannot be seen*
- ◆ *Endless magnification of the image produced by a light microscope yields no extra information*
- ◆ *Wavelengths of electron beams are much shorter than that of light and give the electron microscope much greater resolving power than the light microscope*
- ◆ *Therefore extra magnification up to $\times 250\,000$ yields an equivalent amount of detail.*

The principal features and organelles of a eukaryotic cell as seen by the electron microscope

The electron microscope reveals a wealth of detail of cell structure.

EM part of an animal cell (liver)

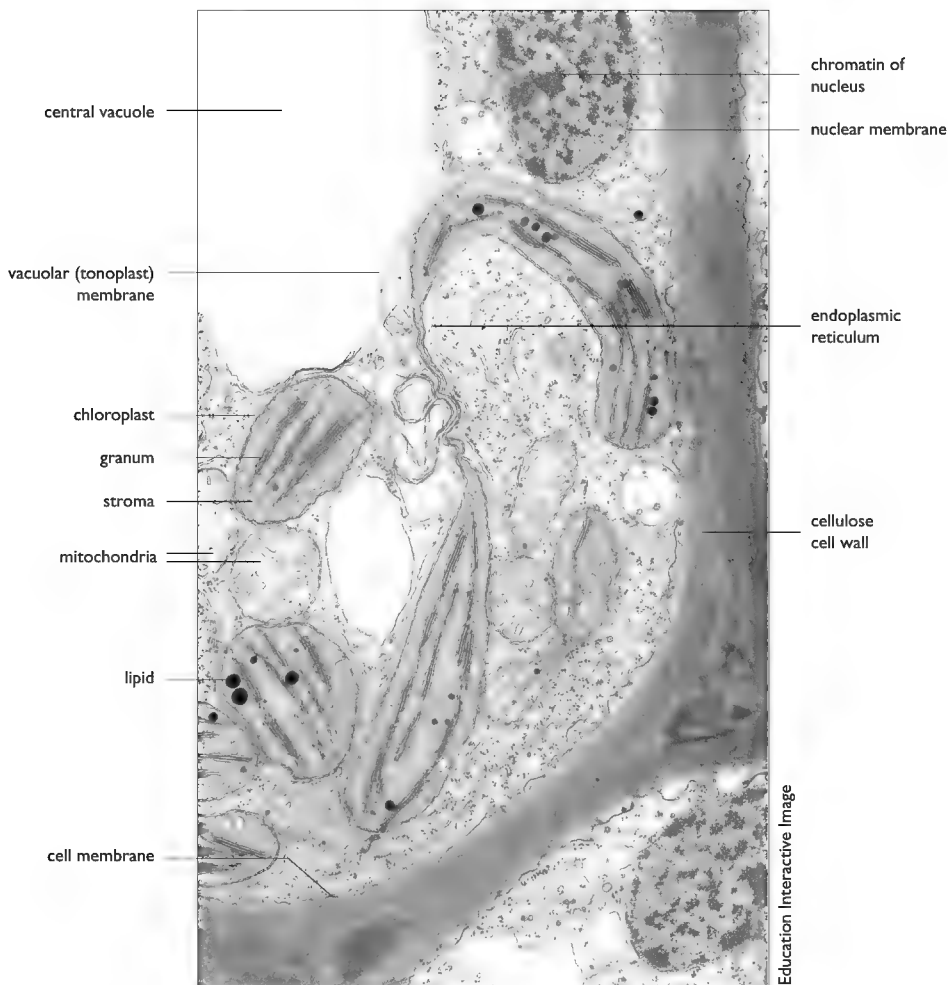


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Nucleus

Even with the optical microscope, the nucleus is clearly visible, having an average diameter in animal cells (liver) of about $5\text{ }\mu\text{m}$, and in plant cells (mesophyll) of about $15\text{ }\mu\text{m}$. The nucleus stands out because of the material **chromatin**, a mixture of DNA and protein, which takes up the stains used in slide preparations. Chromatin is the material of which the chromosomes are made. The nucleus is surrounded by a double membrane, the **nuclear envelope** which

EM part of plant leaf cell



has the same structure as, and is continuous with, the other membrane systems of the cell. Three or four thousand large pores (up to 100nm diameter) perforate the nuclear envelope but the passage of materials in and out is controlled by plugs of protein and RNA which appear to fill the pores. Genes in the nuclear chromosomes direct all the cell's activities and determine its life span and reproductive cycle. The nucleus is rightly called the command centre, but it does not contain all of the genetic material of the cell. Mitochondria and chloroplasts also contain DNA and have genes of their own.

Nucleolus

This is an even more darkly stained region in the nucleus, which consists of a mass of RNA, used in the manufacture of **ribosomes**. Ribosomes are relatively small structures, about 20 nm in diameter, which occur in large numbers, often several thousand per cell either bound to internal cell membranes or free in the cytoplasm. They are built in two sections called sub-units, made of approximately equal quantities of RNA and protein. They act as the sites of assembly for new proteins, manufactured both for export and for internal use.

Rough and smooth endoplasmic reticulum

In addition to the outer surface (plasma) membrane and those which surround the organelles, cells (especially secretory cells), have extensive internal membrane systems, known as the endoplasmic reticulum (**ER**). The ER is a maze of membrane bound tubules and layers of flattened sacs enclosing a fluid filled interior, which acts as an intracellular (inside the cell) transport and storage system. It is continuous with the nuclear membrane and similar in structure.

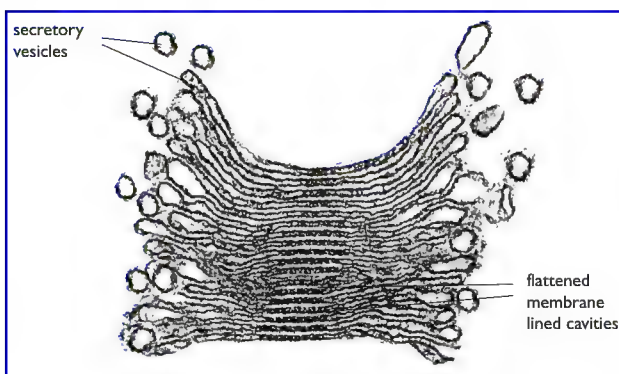
The rough ER has ribosomes associated with it on the cytoplasmic side of the membranes which are the sites of protein synthesis.

The smooth ER tends to be more tubular, and appears to have a complex set of functions, including fat metabolism.

The rough ER and smooth ER are not related in structure or function.

Golgi apparatus

This is more clearly seen in animal cells and is a region of stacked smooth ER specialised for the purpose of collecting, processing and redirecting proteins and fats made in the rough ER. Materials are transported between the ER, the Golgi apparatus, and the plasma membrane, sealed in membrane sacs called vesicles which bud off from one membrane, and then fuse with another. Substances are taken in (**endocytosis**) and expelled (**exocytosis**) by the plasma membrane in this way. For example, digestive enzymes produced by cells of the pancreas are secreted by exocytosis into the pancreatic duct.

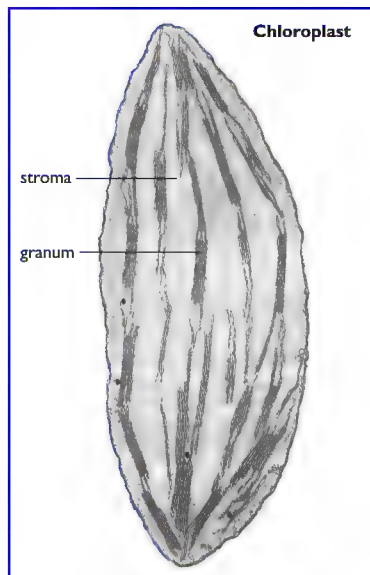


Lysosomes

Some of the vesicles produced by the Golgi apparatus are specialised for particular functions. Animal cells, have lysosomes which contain a cocktail of digesting enzymes. They break down and dispose of unwanted materials or damaged structures in the cell, expelling waste debris by exocytosis, and recycling reusable molecules within the cell. They also meet and fuse with vesicles carrying imported food substances, or immobilised bacteria, from the cell surface, and digest the contents. It is clear from this that the membranes surrounding lysosomes must act as impermeable barriers to the passage of these digestive enzymes. If the contents of a lysosome spilled out into the cytoplasm, for example, the digestive enzymes would digest the cell itself. This process (**autodigestion**) occurs after the death of a cell and plays an important part in its removal.

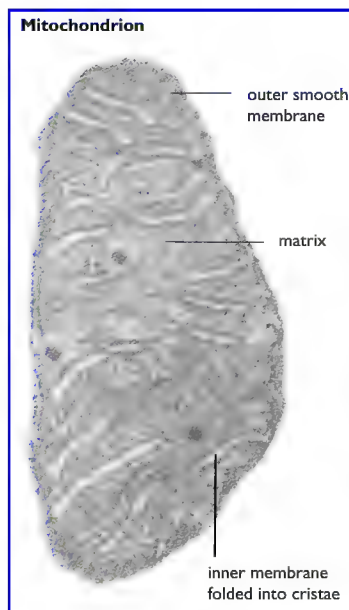
Chloroplasts

contain the green pigment chlorophyll which absorbs light for photosynthesis. In photosynthesis light energy is used in the synthesis of organic compounds (e.g. glucose) from carbon dioxide and water. Chloroplasts, like mitochondria, have a double membrane, but there is also a third membrane system inside the chloroplast called the **thylakoid** membrane system. It is on this that the chlorophyll molecules and enzymes of the light dependent stages are located. The thylakoid membrane system is arranged in the form of stacked discs (**grana**) joined by connecting membranes (**lamellae**). The internal space between the membranes is filled with a fluid (**stroma**) containing enzymes for making organic compounds, e.g. glucose and starch.



Mitochondria

Mitochondria (singular = mitochondrion) carry out aerobic respiration, which transfers energy from energy rich substances such as glucose, into the energy rich substance ATP. High energy consuming tissues like those in the muscles or brain may contain up to a thousand mitochondria in a single cell. Mitochondria are rod-like structures which can vary greatly in length and shape, but are never greater than 1µm in diameter. There is an outer and an inner membrane. The area of the inner membrane is increased by infoldings of the membrane (**cristae**), and it is encrusted on its inner surface with spherical bodies which contain the enzymes for making ATP. The more active the cell, the more cristae and the more enzymes there are, the more the mitochondria increase in size, and increase in number by dividing (they contain their own mitochondrial DNA). The fluid matrix within the inner membrane contains the enzymes responsible for the final stages of the aerobic oxidation of glucose to carbon dioxide and water.



Cytoskeleton An interconnected system of fibrous proteins gives cells their shape and a basis for movement. A number of thread-like protein structures make up the cytoskeleton, notably actin, which forms thin contractile **microfilaments**; and tubulin, a protein which arranges itself into more rigid tubes resembling miniature scaffolding poles called **microtubules**. Microtubules form the supporting skeleton for the tiny cell 'hairs' called **cilia**. Microtubules are also formed and organised within areas called **centrosomes** (microtubule organising centres, or **MTOCs**) which lie very close to the nucleus. During cell division, the centrosome divides to form two new centres of microtubule formation at opposite sides of the cell. A net of microtubules (the spindle) forms between these two new centrosomes on which chromosomes are held and pulled apart.

In animal cells (but not all plant cells) the centrosome contains two structures resembling short cilia, which can be seen in electron micrographs lying at right angles to each other. These are called **centrioles**. Centrioles also form the basal bodies at the base of cilia.

Cellulose cell wall The plant cell wall is made of a fibrous cellulose framework mixed with other materials, notably **pectin**. Pectin is a glue like material (it is used in jam making to set the jelly) and it is concentrated on the surface, sticking adjacent cells together. This sticky region can be seen as a line between the walls of adjacent cells and is called the middle lamella. When the plant cell is fully expanded as a result of the entry of water by osmosis, the cell wall resists further expansion, and the cell is said to be turgid. Turgid cells make a considerable contribution to the support of non-woody structures, e.g. leaves. The cell wall is fully permeable to water and dissolved solutes, but influences the exchange of these across the selectively permeable cell membrane by exerting various physical and chemical forces. The wall is perforated by tiny holes, through which strands of cytoplasm (**plasmodesmata**) pass giving direct communication between neighbouring cells.

In 'woody' parts the cell wall is impregnated with **lignin**. Lignin is a hard, impermeable substance, and lignification typically results in the death of the cell. Such dead lignified tissues are specialised for water transport (eg xylem) and support (eg xylem and sclerenchyma fibres).

◆ CHECKPOINT SUMMARY

- ◆ *The nucleus contains the genetic material (DNA) and can be considered as the control centre of the cell*
- ◆ *Within the nucleus is the nucleolus which is the centre of mRNA and ribosome synthesis*
- ◆ *Rough or granular endoplasmic reticulum is a system of flat sac-like cisternae and interconnecting tubes, which acts as an intracellular transport and storage system*
- ◆ *Ribosomes attached to the RER are centres of protein synthesis*
- ◆ *The rough and smooth endoplasmic reticulum are not related in structure or function, and are not joined. Typically there is less smooth endoplasmic reticulum in plant cells*
- ◆ *The smooth endoplasmic reticulum has a wide variety of functions including fat metabolism*
- ◆ *The Golgi apparatus processes proteins from the RER e.g. forming glycoproteins, which are subsequently released from the cell by exocytosis*
- ◆ *Lysosomes cannot be identified solely on appearance, the activity of digestive enzymes must be demonstrated by other means*
- ◆ *Mitochondria are rod-shaped organelles but appear oval in cross section. Chloroplasts are oval in structure and appear oval in cross section*
- ◆ *Chloroplasts have a double membrane, and an internal thylakoid membrane system which provides a large surface area for the attachment of the pigments and enzymes of the light-dependent stage of photosynthesis. Enzymes controlling the non-light dependent stage are found in the matrix*
- ◆ *Centrioles are involved in the movement of chromosomes in nuclear division, but controversy surrounds the identification of centrioles in plant cells*
- ◆ *Microtubules of protein form a cytoskeleton*
- ◆ *The cellulose cell wall of plant cells is fully permeable to the passage of substances, and protects and supports the cell contents, particularly via its effects on turgidity*
- ◆ *The cell surface membrane has a fluid mosaic structure based on a phospholipid bilayer stabilised with cholesterol, with surface and internal proteins*
- ◆ *It is partially permeable to the passage of solutes, controlling the transport of substances into and out of the cell. The surface proteins and glycoproteins act as recognition sites for antibodies and hormones.*

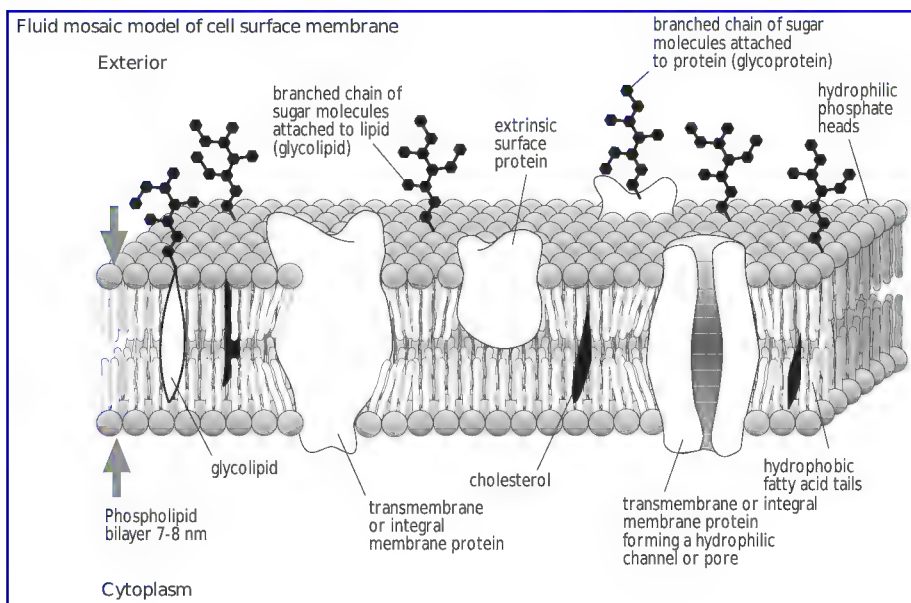
The structure, properties and roles of the cell surface (plasma) membrane

The plasma (cell surface) membrane controls the entry and exit of all materials into and out of all cells. The electron microscope does not reveal any details of its structure, which is modelled on evidence of biochemical investigations. It is fatty in nature and contains proteins and other substances. It is partially permeable, being more permeable to water, than to dissolved solutes which pass through at different rates depending on a complex of factors (see below).

In cells which are specialised for the exchange of materials across the plasma membrane e.g. cells lining the small intestine and parts of the kidney tubules, the surface area may be dramatically increased by extensions known as microvilli.

The cell surface membrane and the membranes which enclose the cell organelles and make up the extensive system of interrelated channels and vesicles within the cell share the same structure. It is a structure which is so flexible that it can break and reform easily yet it is capable of performing complex functions, acting as a barrier, container, transport regulator and as a site of recognition, distinguishing between a wide variety of substances.

The fluid-mosaic model of membrane structure is based on a bilayer of phospholipid molecules, strengthened by cholesterol. Phospholipids adopt this bilayer structure automatically in fluid surroundings because the fatty acid 'tails' of the molecules are water repelling (hydrophobic) whilst the phosphate/alcohol 'heads' are water attracting (hydrophilic).



Proteins of various sizes and shapes are located on and in the bilayer. Some are bonded to the hydrophilic head region and do not penetrate the interior of the membrane (**extrinsic proteins**), others, have one end buried within the fatty layer and one end sticking outside of the cell membrane (**intrinsic proteins**). A third kind, (**transmembrane proteins**), pass all the way through the membrane to create special channels. The carbohydrate component of cell membranes consists of short polysaccharide chains joined to membrane proteins or fats forming **glycoproteins** and **glycolipids** respectively, which project outside the cell membrane.

Individual molecules of phospholipid and protein in the membrane have a degree of **mobility** within the membrane. This fluidity, coupled with the bubbled appearance of the proteins on the surface of membranes gave rise to the the term '**fluid mosaic model**' when the structure was first proposed. Cholesterol stabilises membranes by limiting the movement of phospholipid molecules within the membrane.

Cells have the ability to sense and respond to the presence of a great variety of molecules. This ability is due to proteins in the surface membrane which act as **receptors**. Hormones such as insulin and adrenalin, and many drugs and toxins lock onto recognition sites on receptor proteins triggering changes in the cell's behaviour.

Glycoproteins and glycolipids have a very important role in personalising a cell's identity. They are orientated in the membrane bilayer with the chain of sugar molecules to the outside. The possibility for variation in the structure and different combinations of these chains gives an endless range of different surface patterns, and forms the basis of a recognition system. Each individual has his or her own cell surface 'print'. Self recognises self, and immune systems are mobilised when 'non-self' substances are encountered. The glycoproteins and glycolipids of the cell membrane are responsible for an individual's tissue type, a well known example of which is the blood groups.

Transport across cell membranes

The plasma membrane acts as a partially permeable barrier to the passage of substances into and out of the cell, for example water and fat soluble substances pass through more easily than sucrose. The different rate of passage of electrically charged ions generates membrane potentials, which in turn influence the further uptake of charged ions, and are also involved in cell sensitivity, particularly in nerve cells.

The transport of respiratory gases, nutrients and metabolic waste products occurs through the membrane, either directly through the bilayer, or via channels or 'pores' created by transmembrane proteins. In some cases the substances move down a concentration gradient (i.e. from high concentration to low concentration) which is known as **passive transport**. In others, substances are moved against the concentration gradient (i.e. from low concentration to high concentration) in a process requiring energy in the form of ATP, which is known as **active transport**.

Diffusion and the factors which determine its rate

Molecules and ions may move passively by diffusion, which is defined as the overall (net) movement of substances from regions of their higher concentration (higher chemical potential) to regions of their lower concentration (lower chemical potential) until equilibrium is reached. The movement of the particles of substances in diffusion is random in all directions, as a result of their inherent kinetic energy. If there are more in one area than another, the net effect is for the particles to distribute themselves equally throughout that particular space, i.e. the concentration gradient evens out, until at equilibrium there are an equal number of particles moving in all directions.

The speed of these diffusing particles is only increased by an increase in temperature, which increases their kinetic energy. In addition to the effect of temperature on diffusion, the amount of a substance that diffuses in a given time (rate of diffusion) is dependent upon the difference in its concentration in two separated regions (the **concentration gradient**), the surface area of the separating boundary or exchange surface, and the distance separating them i.e. the thickness of the exchange surface; a relationship expressed in the following equation known as **Fick's law**.

$$\text{Rate of diffusion} = \frac{\text{difference in concentration} \times \text{surface area}}{\text{thickness of the exchange surface}}$$

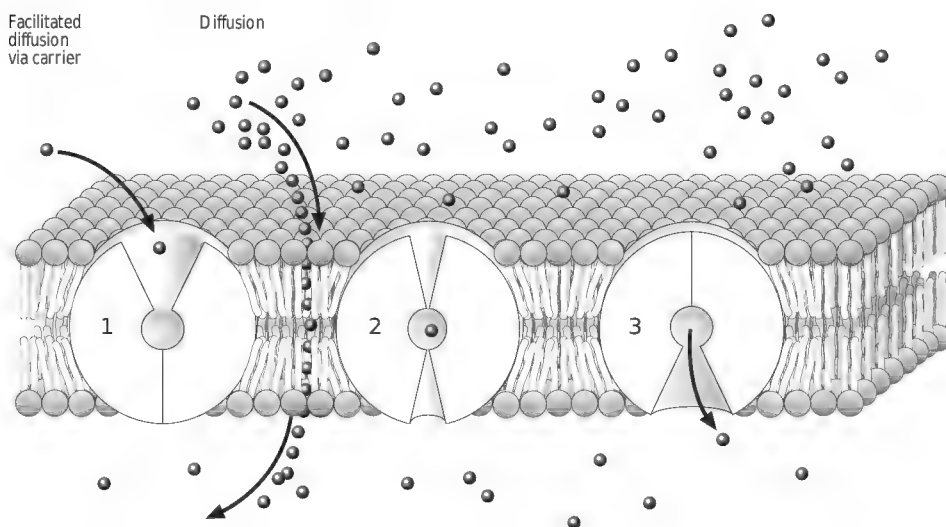
This gives a rough guide to the rate at which a substance such as oxygen, for example, diffuses from the air in an air sac (alveolus) in the lung into the blood in a lung capillary. In principle, the greater the surface area, the greater the concentration difference, and the thinner the separating layers, the greater the rate of diffusion.

The most important factor affecting diffusion across cell membranes, however, is the chemical nature of the substance being transported. Diffusion across the bilayer depends principally upon the solubility of the substance in fat. The phospholipid bilayer is strongly hydrophobic. Polar (charged) molecules such as glucose, some amino acids, and inorganic ions pass through very slowly or not at all, whilst non-polar molecules such as calciferol (vitamin D) move across with ease. It is interesting to note that the first anaesthetics (chloroform and ether) were fat solvents that disrupted membrane structure and function especially in nerve cells.

Facilitated diffusion occurs when non-fat soluble polar molecules e.g. glucose, some amino acids, and inorganic ions, diffuse through hydrophilic channels formed by transmembrane proteins. Polar molecules also become temporarily attached to special binding sites on transmembrane proteins called **carriers**. These are rather like enzymes in that they are shape specific and accelerate a process which is already 'downhill' in terms of energy. All that is needed is a concentration gradient. The attachment of a molecule to the binding site alters the overall shape of the carrier in such a way as to deposit the molecule on the other side of the membrane along their normal concentration gradients.

As has been seen, the transport of inorganic ions such as sodium (Na^+), potassium (K^+), calcium (Ca^{++}) and chloride (Cl^-) across cell membranes depends upon transmembrane proteins. Some transmembrane proteins form selective **ion channels** through which the facilitated diffusion of ions occurs down their concentration gradients. These ion channels cannot be coupled to an energy source, and cannot be involved in active transport across the membrane.

Diagram to show diffusion and facilitated diffusion



Osmosis

Cell membranes are **partially permeable**, allowing the passage of substances at different rates. Generally cell membranes are more permeable to water than to many solutes. Water moves according to the same principles of diffusion, but it is not usual to refer to high and low 'concentrations' of water - the term 'concentration' being traditionally associated with any solutes dissolved **in** water in a solution. Therefore the preferred term is the chemical potential of water or **water potential**.

Water always moves (diffuses) from a region of higher water potential to one of lower water potential. You could think of water potential as the **tendency for water molecules to move** i.e. diffuse. The higher the water potential the more easily the water molecules move, and the lower the water potential the less easily the water molecules move.

At standard pressure and temperature, pure water has the highest water potential. If substances are dissolved in solution then the water potential is decreased because the solutes associate with water to a greater or lesser extent and reduce the ease with which the water molecules can move. Therefore any solution has a lower water potential than pure water, and a more concentrated solution has a lower water potential than a less concentrated solution.

The water potential of a fluid can be described as the tendency of water to move into it from pure water. If the fluid **is** pure water, there is no movement, so the **water potential of pure water is zero**. The water potential of any solution is less than pure water and is therefore negative. The more negative the water potential the greater the tendency of water to move into that system.

Where a solution is separated by a partially permeable membrane from pure water or a less concentrated solution, water will diffuse into the more concentrated solution until equilibrium is reached. The special case of the diffusion of water across a partially permeable membrane is known as **osmosis**.

◆ CHECKPOINT SUMMARY

- ◆ *The cell surface membrane acts as a partially permeable membrane regulating the transport of substances across the membrane*
- ◆ *Passive diffusion occurs across membranes down diffusion gradients from high concentration to low concentration. Fat soluble substances diffuse faster than non-fat soluble substances which must pass through the aqueous pores*
- ◆ *The speed of these diffusing particles is only increased by an increase in temperature, which increases their kinetic energy*
- ◆ *In addition to the effect of temperature on diffusion, the amount of a substance that diffuses in a given time (rate of diffusion) is dependent upon the difference in its concentration in two separated regions (the concentration gradient), the surface area of the separating boundary or exchange surface, and the distance separating them i.e. the thickness of the exchange surface*
- ◆ *Facilitated diffusion is diffusion via special carriers which ease the passage of substances through the membrane*
- ◆ *Water always moves across the cell surface membrane passively by osmosis*
- ◆ *Osmosis is the special case of the diffusion of water from regions of higher water potential to regions of lower water potential across a partially permeable membrane which is more permeable to water than to dissolved solutes. (If the membrane was fully permeable the solutes would diffuse down their diffusion gradient and the water would not move)*
- ◆ *At room temperature and pressure pure water has the highest water potential which is given the value of zero. Solutions have a water potential of less than zero (negative)*
- ◆ *Increasing pressure increases the water potential and it can become positive, in other words water can be 'squeezed' out of solutions through partially permeable membranes into pure water*
- ◆ *Active transport involves energy in the form of ATP from respiration to pump ions across the cell surface membrane via carriers against their diffusion gradient*
- ◆ *Mass or bulk transport of fluids into and out of the cell is achieved by vacuoles fusing with, or being pinched off from, the cell surface membrane respectively.*

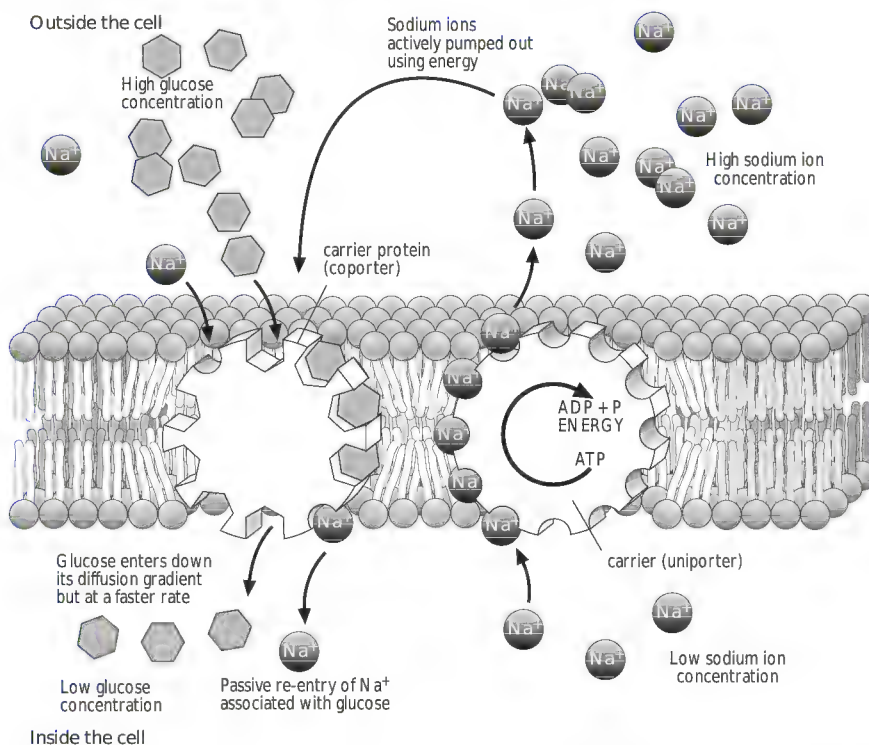
Active transport

Some transmembrane proteins act as active **ion pumps**, which use energy from ATP from respiration, to move ions against their concentration gradients. The ion channels can open and close like 'gates', and the activity of the ion 'pumps' can be varied. In these ways, the membrane can be made selectively permeable to certain ions at certain times.

As a result of the distribution of ions on either side of the membrane, **transmembrane potentials** are created, in which there is an overall difference in electric charge between the inside and the outside of the membrane. In normal conditions, the inside of the cell membrane is negatively charged relative to the outside, and this will assist the uptake of positively charged ions (cations) and oppose the uptake of negatively charged ions (anions). Thus the movement of ions across membranes is influenced by both electrical and chemical gradients i.e. **electro-chemical gradients** (these have particular importance for the function of nerve and muscle cells).

Some of these transmembrane protein carriers carry two substances at once in a **coupled mechanism**. A common example is the sodium/potassium pump (Na^+/K^+ pump), in which the active pumping of sodium out of a cell is coupled with the pumping of potassium in, both against their diffusion gradients. For every two

Diagram to show active transport (ion pumps)



sodium ions pumped out, three potassium ions are pumped in, resulting in high potassium and low sodium levels within the cell. Another example is where the sodium pump is linked to the uptake of glucose. The sodium ions are pumped actively out of the cell and diffuse back into the cell via a carrier associated with glucose. In this case the glucose is moving passively down its concentration gradient, but at a faster rate as a result of its association with the re-entry of sodium which is kept at a high rate by its being continually and actively pumped out of the cell.

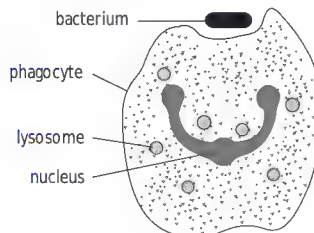
Endocytosis and exocytosis

The bulk transport of liquids and solids is achieved by membranes pinching off small bubble-like vesicles which can fuse with other membranes to transfer their contents. Uptake of substances into the cell in this way is known as **endocytosis**, and elimination of substances as **exocytosis**.

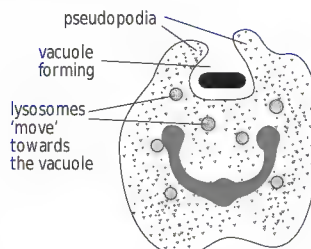
The term **phagocytosis** is used to describe the kind of endocytosis in which relatively large solid particles are 'ingested' by a cell, as in the case of white cells which engulf bacteria, or *Amoeba* taking in food. In this process the outer membrane folds inwards to completely surround the ingested particle. It is then transported into the interior of the cell within a sealed vesicle which functions as a temporary digestive chamber and, in *Amoeba*, is termed a food vacuole. Lysosomes containing digestive enzymes fuse with and release their contents into the food vacuole and the soluble products of digestion are transported out for assimilation by the cell. Undigested matter may be expelled from the cell by the reverse process (exocytosis)

Fluid secretions produced by cells are transported to the plasma membrane in small vesicles which fuse with it and release their contents by exocytosis. This process is sometimes referred to as **pinocytosis**.

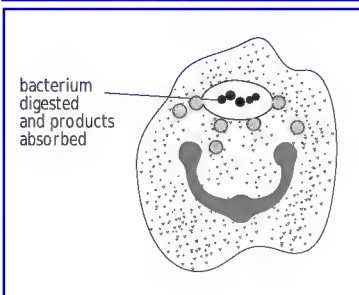
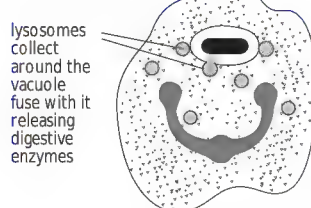
Phagocyte 'moves' towards bacterium



Vacuole forming



Vacuole formed

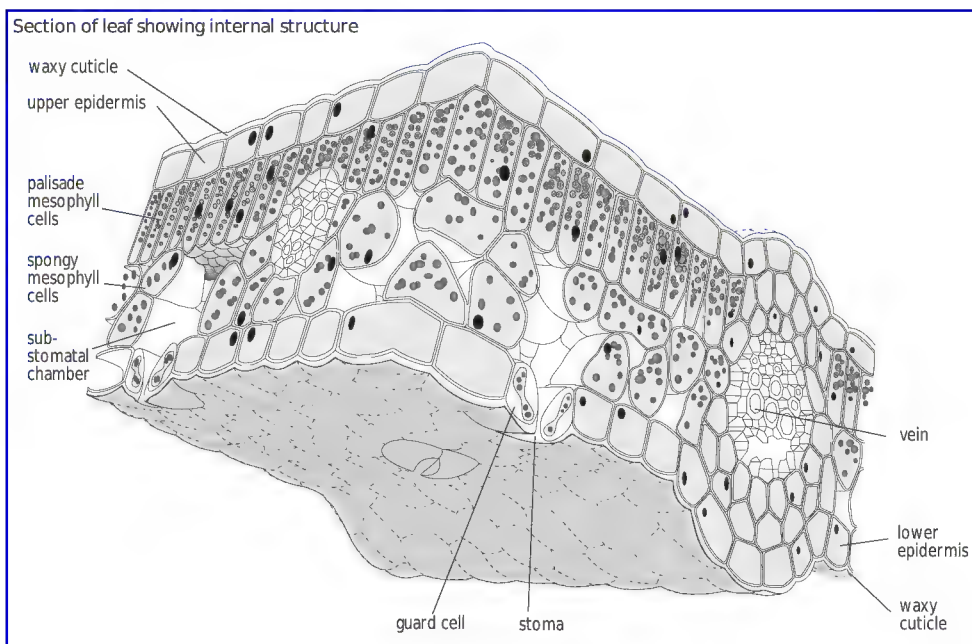


Aggregations of cells

The leaf palisade and liver cells illustrated at the beginning of this unit were chosen to represent typical plant and animal cell features. In life they are grouped with other similar cells performing the same functions into cell aggregations called **tissues**.

The leaf and the liver are **organs**, made up of different tissues organised to carry out a particular function or related functions

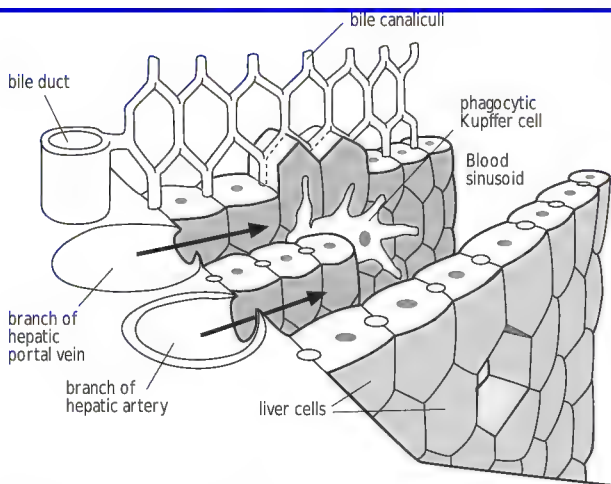
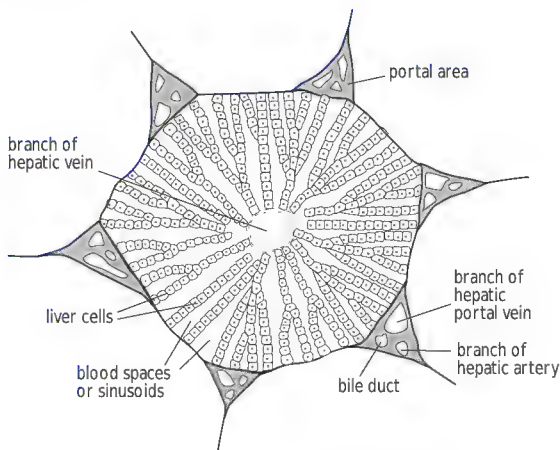
The leaf is an organ specialised for photosynthesis. It consists of various tissues: epidermal tissue of transparent cells with no chloroplasts which secrete a waxy layer (cuticle) and form a protective layer on the leaf surface; palisade tissue forms the photosynthetic layer; spongy mesophyll consists of large, loosely packed, thin walled cells with few chloroplasts, specialised to form a gas exchange surface; and the leaf veins are made up of vascular tissues, xylem and phloem, for the transport of water and organic solutes.



Unit 1: Molecules and Cells

The liver is an organ of metabolic control, monitoring and controlling large numbers of chemical reactions to help maintain constant optimum internal conditions (homeostasis), e.g. blood glucose levels. It consists of various tissues: sheets of liver cells, blood vessels, bile canaliculi (small ducts) and connective tissue.

Liver lobule



The so called 'classic' liver lobule is only seen in the pig liver, in other animals the structure of the liver is far from clear. The blood flows from the portal area, through the blood sinusoids, into the central vein. As it passes over the large surface area of the liver cells the various adjustments are made.

1.4

The Cell Cycle

Content

Chromosome structure

- ▼ Chromosome structure of DNA and histones in the nucleus of eukaryotic cells
- ▼ The replication of DNA, the role of the enzymes involved (see 1.1)
- ▼ A leaf palisade cell and a liver cell as cells with a diploid chromosome number which have been produced by nuclear division followed by differentiation

Mitosis

- ▼ Mitosis: the behaviour of chromosomes during the stages of the mitotic cell cycle, the events of prophase, metaphase, anaphase and telophase
- ▼ The significance of mitosis in growth and replacement; the significance of daughter nuclei with chromosomes identical in number and type
- ▼ The nature of natural and artificial cloning in plants and animals

THE CELL CYCLE

Introduction

The events that occur in the life of a cell are known as the cell cycle. Some cells are capable of repeated divisions (apical meristems at the tips of roots and shoots in plants, and the germinal epithelium in the epidermis of the mammalian skin), and they have a repeated cycle of events resulting in the production of daughter cells. Most cells, however, become differentiated into specialised cells which lose the ability to divide (terminal differentiation).

Interphase refers to the greater part of the life of a cell when there is no visible activity. If the cell is going to divide the chromosomes appear and nuclear division occurs by a process known as **mitosis**. When the nucleus has divided, the rest of the cell (cytoplasm and plasma membrane) divides in a process known as **cytokinesis**. Together, interphase, mitosis and cytokinesis make up the **cell cycle**. The term interphase should not be interpreted to mean that the cell is resting. Interphase can itself be divided into three distinct periods called G₁, S and G₂. ('G' refers to the 'gaps' between DNA replication and mitosis.)

G₁ is by far the longest period of the cell cycle. During G₁, the cell machinery carries out protein synthesis, and growth occurs. All the cells of the body have identical sets of genes in their nuclei but the cells develop in different ways to perform different functions. This development process is called cell differentiation in which different genes are switched on and off so that only one small part of the genetic code is active in each cell.

After a period of growth and differentiation, the length of which depends upon a variety of internal and external factors, protein synthesis is suspended, and the DNA set replicates itself. This is the **S** phase. DNA replication is followed by another 'gap' period, **G2**, before mitosis starts, in which the cytoskeleton of the cell breaks down and the microtubule components begin to reassemble into spindle parts. Without a cytoskeleton, the cell assumes a more spherical shape (see prophase).

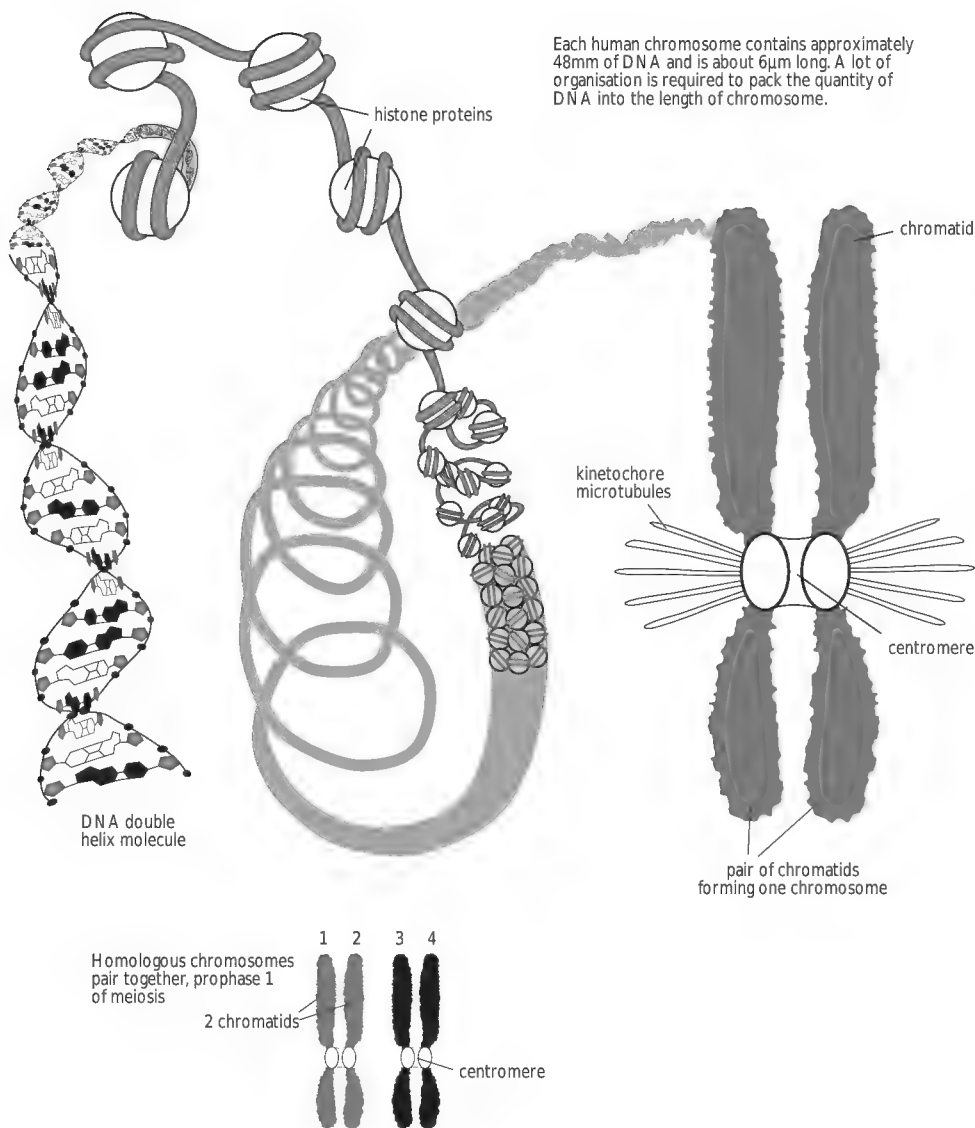
The timing of events within the cell cycle is extremely variable. In ideal conditions, where food and oxygen are in plentiful supply and temperature and pH values are optimal, bacterial cells can complete the cycle to produce a new generation every 20 minutes. Other cells, for example muscle cells, never complete the cycle and remain stuck in G2 until they die, a condition called terminal differentiation.

Chromosomes structure

DNA is the carrier of the genetic code by which hereditary information is passed from generation to generation via the nuclei of the gametes and from cell to cell via the nuclei of the cells produced by division of the fertilized egg. In a non-dividing cell, the nucleus contains scattered '**chromatin**' material which is a mixture of DNA and an associated protein called **histone**. When the DNA is in this dispersed form seen in the non-dividing nucleus, it is genetically active, sending out information to the cytoplasm to control the complex of cell processes. When the cell is about to divide the chromatin concentrates or condenses into an inactive state to form the **chromosomes**. In this state the DNA is more resistant to damage during the processes of nuclear and cell division. Moreover, since it is in discrete bodies like the chromosomes, the division of the genetic material between the nuclei can be carefully controlled, reducing the danger of any being lost. It is only in this condensed form that chromosomes are ever visible in the cell and this only happens during cell division, so the familiar ribbon like image of a chromosome is not representative of its active state.

Chromosomes consist of a centromere and two 'arms', the relative lengths of which depend on the position of the centromere. As a result of the replication of DNA before their appearance, chromosomes appear as double structures known as 'sister chromatids'. A chromatid is in effect a new chromosome, but while they remain attached by a single centromere, they are referred to as sister chromatids.

The nucleus of each cell of a **diploid** organism contains two sets of chromosomes; one maternal from the female gamete and one paternal from the male gamete. As a result, each chromosome has a 'partner' in the other set which carries genes for the same characteristics. Two such chromosomes are said to form a **homologous** pair. The nucleus of the palisade cell and that of the liver cell, described in 1.3 are diploid. The cells were produced by divisions of a parent cell by the process of mitosis, described below, in which the DNA is copied exactly (replicated). DNA replication is described in Unit 1.1 and you will find it helpful, before starting this module to read through the section on DNA.



When cells are first formed by the process of division they all look much alike. At a very early stage, however, they start to behave differently as different genes are 'switched' on and off with the result that groups of cells (tissues) become specialised for a particular function. The process of cell specialisation is called **differentiation**. The leaf palisade cell and liver cell described above are produced by nuclear division (mitosis) and cell division followed by differentiation.

Mitosis

Mitosis is the process by which the genetic material of a dividing cell, contained within the DNA of chromosomes, is copied into two new genetically identical 'daughter cells'. Mitosis occurs in the cell division seen in growth, repair, the replacement of cells which have a limited life span like our red blood cells and skin cells, and in asexual reproduction in many plants and lower animals.

The main stages of mitosis

Chromosomes only become visible when stained and viewed under the light microscope when the nucleus of a cell is just about to divide. This is because only at this time is the DNA/histone mixture wound up (condensed) as tightly as it can be. By this stage the DNA has also copied itself (replicated) so each chromosome appears double, and joined at one point (the centromere). Whilst they remain joined in this way the two daughter chromosomes are referred to as sister chromatids.

Nuclear division (mitosis) occurs in four main stages, namely prophase, metaphase, anaphase and telophase.

Prophase is the first phase of mitosis, and as it begins, the DNA has already replicated, all protein synthesis has stopped, and each chromosome is condensed into the characteristic double chromatid form. At the same time the cell rounds up, the nuclear membrane

breaks down into small fragments, and a spindle of microtubules forms between two microtubule organising centres (MTOCs) at opposite poles of the cell.

Metaphase is defined as when the chromosomes become attached to the spindle by structures called kinetochores. Kinetochores consist of microtubules and 'motor' proteins which utilise ATP energy to pull on the spindle. The effect of both sets of kinetochores pulling in opposite directions is that the chromosomes line up along the middle (equator) of the spindle.

Anaphase is defined when quite suddenly, and all at once, the chromatids of each pair separate, with each being pulled under tension in opposite directions towards the poles of the cell.

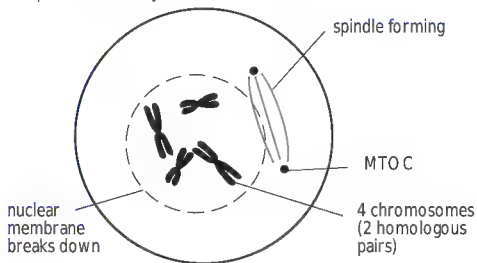
Telophase is the stage when the two new, identical sets of chromosomes reach the opposite poles and a new nuclear envelope forms to surround each set.

Nuclear division by mitosis is followed by division of the cytoplasm into two equal parts. This process is called **cytokinesis** and it occurs differently in animals and plants. In animal cells the spindle disintegrates during telophase and the microtubule components reassemble into a new cytoskeleton. The equator of the cell is constricted by a ring of contractile proteins (actin) in the process of cleavage, to create two roughly equal cells.

In plant cells the spindle lingers a little longer and seems to act as a guide to bring Golgi apparatus and associated secretory vesicles to the equator. The vesicles deposit their contents, which are the building constituents of a new cell wall, on the equator to form a plate of deposited material (the cell plate). Some of the vesicles remain intact and make connecting channels through the new cell wall (plasmodesmata).

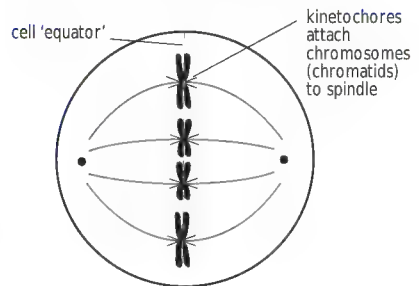
1 Prophase

Cell is rounded
MTO C's migrate to opposite poles
nuclear membrane disintegrates
spindle formed by MTO C's



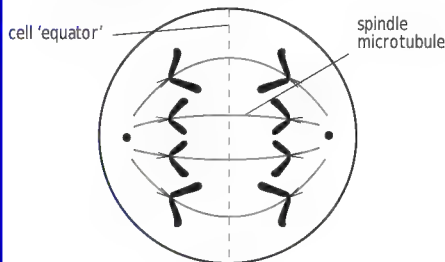
2 Metaphase

Chromosomes held on 'equator' of cell
under tension. MTO C's at opposite poles



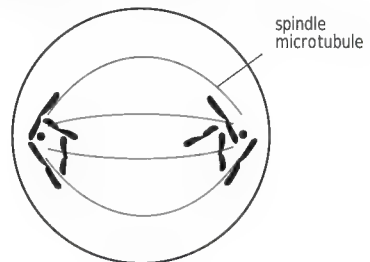
3 Anaphase

Chromatids separate and move towards
opposite poles

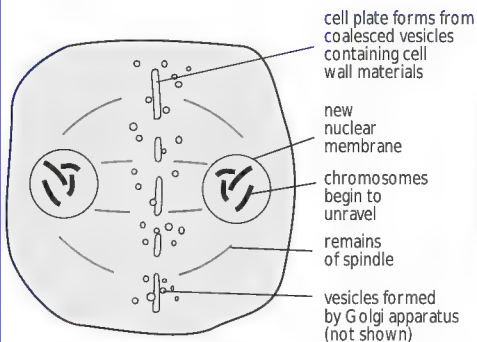


4 Telophase

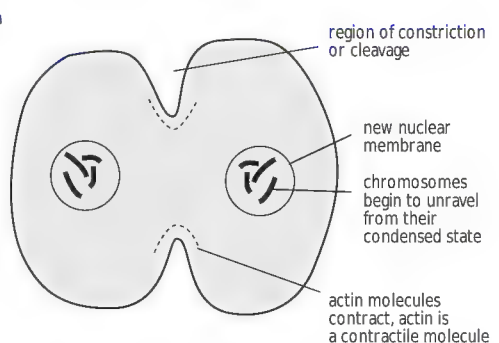
Chromosomes form beginnings of new nuclei at
opposite poles, nuclear envelope reforms



Cytokinesis in plant cells



Cytokinesis in animal cells



The significance of mitosis

The development of a multicellular organism from a fertilised egg by mitosis, means that all the cells of the body are genetically identical to the fertilised egg. The development of an organism from the fertilised egg is the story of the controlled expression of this genetic information, with only a small fraction of the genes being expressed in cells as they differentiate to form tissues specialised for specific (and limited) functions. In mature cells most of the DNA is inactive all of the time.

Asexual reproduction does not involve the fertilisation of gametes, and as a result of mitosis produces offspring which are genetically identical to each other (clones). Many multicellular organisms, especially plants can reproduce their entire bodies in this way, either from specialised structures eg. strawberry runners, or single celled spores.

The production of genetically identical cells in the growth and development of multicellular organisms allows certain cells to retain the ability to develop into any other if needed as a result of some damage, for example stem cells in mammals can divide to form any of the different types of blood cell. In the asexual reproduction of organisms it allows the rapid exploitation of optimal conditions, where any variation would be disadvantageous.

Natural and artificial cloning in plants and animals

Clones are genetically identical organisms. Cloning may occur naturally, for example, identical twins in humans, binary fission in microorganisms and vegetative reproduction in plants, but it can also be achieved artificially. The advantages to agriculture of cloning techniques are obvious; to be able to select the very best crop plant or farm animal and multiply it indefinitely has been the dream and ambition of farmers throughout the ages. Plant growers, since the earliest times, have used the natural properties of plants to multiply by vegetative (asexual) means; indeed some common crop plants, for example the banana, can only be grown by cloning. The cloning of animals is a relatively recent phenomenon, made possible by new techniques for manipulating embryonic cells, and whilst it opens up some exciting new biotechnological horizons, for many it also raises new ethical and legal questions.

◆ CHECKPOINT SUMMARY

- ◆ *Chromosomes consist of DNA and histones (protein only found in the nucleus) in the nucleus of eukaryotic cells*
- ◆ *Chromosomes only form just prior to nuclear division, either mitosis or meiosis*
- ◆ *Before their formation the DNA has replicated in the S phase of interphase, replication is semi-conservative and controlled by enzymes e.g. DNA polymerase*
- ◆ *Leaf palisade cells and liver cells have a diploid chromosome number and have been produced by nuclear division followed by differentiation. Differentiation limits further division*
- ◆ *Chromosomes consist of a kinetochore (centromere) which is the centre of chromosome movement, and two arms of variable length depending on the position of the centromere*
- ◆ *Telomeres are found at the end of the arms of chromosomes*
- ◆ *When stained and viewed under UV light a characteristic pattern of light and dark banding can be seen to be unique to each chromosome of a haploid set*
- ◆ *In prophase of mitosis the chromosomes form from the chromatin of the nucleus and appear as double structures made of two chromatids*
- ◆ *In metaphase they align on the equator of the nuclear spindle apparatus (NSA) formed from the nuclear membrane*
- ◆ *In anaphase the kinetochore divides and the chromatids separate to the poles of the NSA under the control of the centrioles*
- ◆ *In telophase each of the two sets of separated chromatids (now considered as new chromosomes) become surrounded by nuclear membranes and disperse as chromatin in the new daughter nuclei*
- ◆ *A new cell forms around each of the two daughter nuclei.*

Producing crops by vegetative propagation

Most plants can reproduce asexually, as anyone who has planted a sprouting potato, or taken a geranium cutting will know. This kind of reproduction, which does not involve gametes and the production of seeds, and results in genetically identical copies, or clones, of the parent plant is called **vegetative reproduction**. Over the centuries, crop growers have exploited the natural asexual reproductive properties of plants to multiply selected varieties. Many important food crops such as potatoes, sugar cane and bananas have been developed almost entirely by vegetative propagation.

There are obvious advantages in selecting a single superior individual from a plant population and reproducing it asexually. Since members of a clone are genetically uniform under optimum conditions, they grow to the same height, flower at the same time, and produce fruit of a similar size, features which make them highly suitable for mechanised farming. Vegetative propagation may be used to multiply infertile plants which have arisen from chance mutations but have commercial value, e.g. seedless fruits.

There are, of course, inherent risks in growing large numbers of plants with identical genotypes. The uniformity which makes them so attractive to farmers applies also to their susceptibility to pests, diseases and other environmental hazards. An entire crop may be wiped out by a single type of pathogen. Another drawback is the cost of vegetative propagation. By comparison with seed planting, it is more expensive per plant because it is more labour intensive, and it requires a large capital investment for research and technical facilities. Some plants, notably apple, pear, peach and cherry trees, have proved impossible to multiply by cuttings, but may be propagated vegetatively by the technique of grafting.

Clones may be propagated on for many generations. The Cabernet Sauvignon grape, for example, has been cloned for at least 2000 years, but repeated vegetative propagation can bring about serious disease problems. Without the natural break provided by seed formation and the opportunity for a new virus-free seedling each generation, cloned plants may retain their disease organisms from year to year, and these pathogens may evolve into more virulent strains. For this reason, it is necessary to plant new source vineyards regularly (from seed stock or micropropagated lines), to patent new plants, and to keep accurate records determining the pedigree of the source clone.

'Seed' potatoes are produced by vegetative reproduction from virus free plants grown in areas of windy and wet conditions (Scotland and Ireland) where the aphid (greenfly) carriers (vectors) of many virus diseases cannot easily fly to infect crops. These 'seed' potatoes are bought in, when virus diseases begin to accumulate to levels which decrease crop yield in growing regions. It is not efficient to keep growing potato plants from potatoes kept from the preceding year's crop. New varieties of potatoes are grown from true seeds.

It is now possible to clone plants from cell cultures through the techniques of **micropropagation**. Typically from apical meristems (dividing cells of shoot tips) which are virus free. In some cases, whole new plants can be propagated from single cells. By these techniques new, genetically engineered varieties may be cultured and multiplied rapidly. Plants which are transformed in this way to contain DNA from other organisms are called **transgenic plants**.

◆ CHECKPOINT SUMMARY

- ◆ *Mitosis is nuclear division in which the daughter nuclei have the same chromosome number as the parent nucleus, typically diploid nuclei producing diploid daughter nuclei*
- ◆ *The daughter nuclei are therefore genetically identical to the nucleus of the cell that produced them (except for any mutations that may occur)*
- ◆ *As a result of mitosis in the growth of an organism from the fertilised egg all cells therefore are genetically identical*
- ◆ *The production of genetically identical cells with the full set of genetic information allows the replacement of any cells in repair processes*
- ◆ *Mitotic cell division is seen in growth, repair and asexual reproduction*
- ◆ *The production of new individuals involves the transfer of genetic information from parent to offspring*
- ◆ *Mitosis results in cells identical to the fertilised egg reaching the reproductive organs*
- ◆ *Mitosis results in all offspring of asexual reproduction being genetically, lacking genetic variation*
- ◆ *In the asexual reproduction of organisms it allows for the rapid exploitation of optimum conditions where any variation would be disadvantageous.*

The cloning of animals

Identical animal clones can be produced by simulating the natural process by which identical twins are formed, in other words, by splitting apart the cells of developing embryos at a very early stage after fertilisation. Cows or sheep selected for a particular, desired characteristic may be inseminated artificially with semen from a selected bull and the embryonic ball of cells (**blastula**) is collected from the cow before it naturally implants. Under a microscope the blastula can be divided into two or more 'twins' which are cultured on for a few days, then implanted into a surrogate mother treated with hormones so that her oestrus cycle coincides exactly with the real mother. Alternatively, the blastula can be frozen in liquid nitrogen and stored for later use. This technique is called **embryo transfer**.

A rather more sophisticated extension of these cloning techniques with farm animals is the **nuclear transfer** procedure. Unfertilised eggs are harvested from a donor animal and their nuclei are removed by suction with a micropipette. The 'enucleated' egg cells may then be fused with single cells taken from a selected blastula. Fusion is normally achieved by applying a small electric current to the culture medium. The egg, now equipped with a super selected genotype (set of genes), is grown in culture for a few days, then implanted into a surrogate mother, or frozen. The advantage of this method is that the same selected blastula may yield 30 or 40 cells for nuclear transfer, each of which can be implanted into surrogate mothers and grow into an adult. Furthermore, the original donor may be treated with fertility hormones to repeat the process every three months.

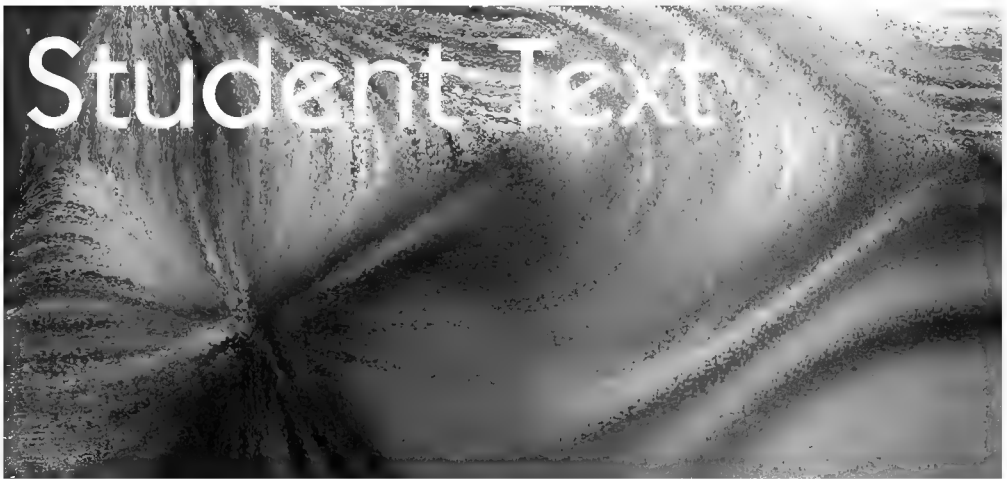
The technique of nuclear fusion described above has been used to insert the genotype of an adult body cell into an unfertilised egg, then brought to birth in a surrogate mother. Dolly, the famous sheep, was cloned in this way from cells taken from the mammary glands of its genetic mother.

Unlike plant cells, animal cells can not be induced to grow into whole new organisms once they have begun the process of differentiation. The only time this is possible is before the onset of differentiation, in other words, at the egg or zygote stage. The possibilities for creating transgenic animals is therefore very much more limited in animals than in plants. Now that the procedures for embryo transfer and nuclear transfer are improving, the possibilities for genetic modification and the creation of transgenic animals are rapidly expanding. Pigs, genetically modified to reduce the rejection response from a human organ recipient, may soon be cloned successfully to provide kidneys and other organs for transplantation. This is another field of research which raises ethical issues of public concern over which much debate will surely follow.

◆ CHECKPOINT SUMMARY

- ◆ Clones are genetically identical organisms
- ◆ Cloning may occur naturally, for example, identical twins in humans, binary fission in microorganisms and vegetative reproduction in plants, but it can also be achieved artificially
- ◆ The production of crops by vegetative propagation e.g. in which cuttings are taken from a desirable original is a form of cloning, some common crop plants, for example the banana, can only be grown by cloning
- ◆ Since members of a clone are genetically uniform under optimum conditions, they grow to the same height, flower at the same time, and produce fruit of a similar size, features which make them highly suitable for mechanised farming
- ◆ The uniformity which makes them so attractive to farmers applies also to their susceptibility to pests, diseases and other environmental hazards. An entire crop may be wiped out by a single type of pathogen
- ◆ It is now possible to clone plants from cell cultures through the techniques of micropropagation. In some cases, whole new plants can be propagated from single cells
- ◆ This is useful in producing virus free stock from apical meristem cells which viruses do not penetrate
- ◆ The cloning of animals is possible by new techniques for manipulating embryonic cells, e.g. by splitting apart the cells of developing embryos at a very early stage after fertilisation.

Biology



Unit 2B

Exchange Transport and Reproduction

FELTHAM PRESS

Exchange, Transport and Reproduction

Contents

2B.1	
Exchanges with the Environment	1
▼ Exchanges with the environment	
▼ Exchange processes	
▼ Gas exchange in protozoa	
▼ Gas exchange in flowering plants	
▼ Gas exchange in humans	
▼ Digestion and absorption	
2B.2	
Transport Systems	17
▼ Transport systems	
▼ Transport in flowering plants	
▼ Movement of water	
▼ Movement of nutrients	
▼ Transport in mammals	
▼ Blood and body fluids	
2B.3	
Adaptations to the Environment	51
▼ Structural adaptation	
2B.4	
Sexual Reproduction	55
▼ Sexual reproduction	
▼ Reproduction in flowering plants	
▼ Reproduction in humans	

Exchange, Transport and Reproduction

2B.1

Exchanges with the Environment

Contents

Exchanges with the environment

- ▼ The exchange of respiratory gases; nutrients; excretory products.

Exchange processes

- ▼ The relationship of size and surface area to volume ratio.
- ▼ The features of exchange surfaces which aid passive and active transport.
- ▼ The special features of gas exchange surfaces.
- ▼ The need for ventilation mechanisms.

Gas exchange in protozoa

- ▼ How gas exchange is achieved in a protozoan.

Gas exchange in flowering plants

- ▼ The external and internal structure of a mesophyte leaf.
- ▼ The structure and roles of stomata and the mechanism of stomatal opening in terms of changes in ion concentrations leading to changes in turgidity.

Gas exchange in humans

- ▼ The structure of the thorax.
- ▼ The mechanism of ventilation, including the role of the pleural membranes.
- ▼ How breathing is controlled; vital capacity and tidal volume.
- ▼ The structure of alveoli and their role in gas exchange.
- ▼ The function of surfactants.
- ▼ The control of breathing by the respiratory centre in the brain.

Digestion and absorption

- ▼ The structure of the alimentary canal in relation to digestion and absorption.
- ▼ Mastication and movement of food along the gut.
- ▼ The histology of the ileum wall.
- ▼ The sources and effects of secretions concerned with the digestion of carbohydrates.

EXCHANGES WITH THE ENVIRONMENT

All living cells obtain oxygen and nutrients from, and excrete waste substances into, the fluid environment which surrounds them. In the case of single celled organisms, the fluid environment is the habitat in which they live, normally fresh or salt water. The individual cells of multicellular organisms are surrounded by a fluid medium called **tissue fluid** or extracellular fluid, with which they exchange materials. This is referred to as the '**internal environment**' and for exchange to occur between the internal and the external environment in larger organisms, specialised systems have evolved.

Exchange processes

Smaller organisms have larger surface area to volume ratios (surface area divided by volume) than larger ones.

This means that in smaller organisms all parts of their body are close enough to the surrounding medium not to require a specialised transport system. In unicellular and small multicellular organisms oxygen, carbon dioxide and waste materials may be transported by simple diffusion between the external and internal environments. Internal transport by diffusion is further aided by the particular shapes of some organisms and their parts. For example in the jellyfish and sea anemones there is a large body cavity which is filled with the external medium (water), effectively doubling their surface area in contact with the sea water; in the Platyhelminthes (the 'flat' worms eg the tape worms and liver flukes) there is a flattened body shape, and flowering plants have leaves with a flattened form with large internal air spaces.

In large multicellular organisms the external surface area is increased relative to the body volume by specialised exchange surfaces, e.g. lungs, with huge surface areas. These provide for rapid and efficient exchange of gases, nutrients and waste substances with the environment.

The exchange of substances is by **passive diffusion** and/or **active transport**.

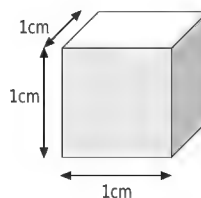
In passive diffusion the rate is dependent upon the concentration gradient between the external environment and the exchange surface, and the distance travelled. In general it conforms to the following equation, known as Fick's law.

$$\text{Rate of diffusion} = \frac{\text{surface area} \times \text{difference in concentration}}{\text{thickness of the exchange surface}}$$

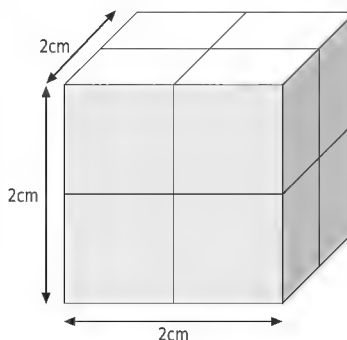
In principle, the greater the surface area, the greater the concentration difference, and the thinner the separating layers, the more rapid the diffusion.

Surface areas for exchanges are increased dramatically by dividing them up into small components, e.g. gill lamellae or alveoli in the lungs, and the separating layer is made from flattened epithelial cells which minimise the distance between the environment and the blood.

Gas exchange surfaces have a large surface area, which is well supplied with capillaries of the blood vascular system, and thin to reduce the diffusion distance between the external medium (air or water) and the blood. If the external medium is air, there is an



Surface area = 6cm^2
Volume = 1cm^3
Surface area to volume = $6:1 = 6$



Surface area = 24cm^2
Volume = 8cm^3
Surface area to volume = $24:8 = 3$

unavoidable loss of water over the surface so it is covered with a layer of water, and mucus is secreted to reduce losses by evaporation.

These delicate systems are protected in specialised internal organs, e.g. lungs, gills; and require mechanisms to move the external medium (air or water) over the surface. Such mechanisms are called ventilation mechanisms (note that flowering plants do not possess a ventilation mechanism and rely solely on diffusion gradients). In fish and mammals the ventilation mechanisms involve muscular contractions which serve to maintain a constant flow of water or air over the gas exchange surfaces. The process of air or water intake is called **inspiration** and the expulsion of air or water is called **expiration**. They are also supplied with blood by mass transport circulatory systems for the rapid and efficient transport of substances to and from the external medium, and between the different tissues and organs.

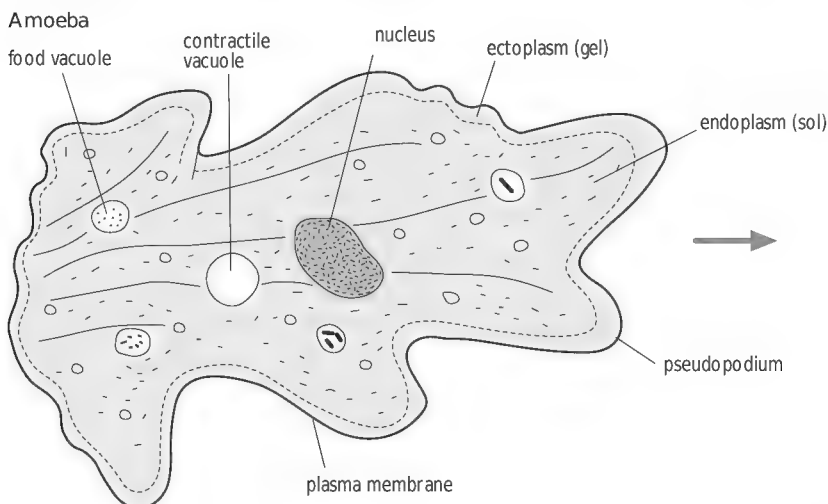
The uptake of digested nutrients from the gut into the blood also involves **active transport**, and the epithelial cells lining the gut are specialised for this purpose, being equipped with numerous mitochondria to supply energy demands and microvilli to increase their surface area.

Gas exchange in protozoa (protocists)

Protocists are single celled eukaryotic organisms (previously referred to as protozoa and algae) e.g. *Amoeba*. They are microscopic (the larger species just being visible to the naked eye) so have a large surface area to volume ratio, and do not possess special structures for gas exchange. Not only can oxygen and carbon dioxide be exchanged efficiently across the surface, they have the additional advantage of being able to excrete nitrogenous waste in the form of ammonia (NH_3). Ammonia is very toxic but very soluble and quickly diffuses out of single celled aquatic organisms. In most larger multicellular animals ammonia can not be tolerated in the tissue fluids and is converted to urea or uric acid for excretion by specialised organs, e.g. the kidneys in vertebrates.

◆ CHECKPOINT SUMMARY

- ◆ Living organisms need to take up nutrients, exchange respiratory gases, which includes an element of excretion in the elimination of carbon dioxide, and eliminate other excretory products.
- ◆ Surface area increases with increasing size but the surface area to volume ratio decreases.
- ◆ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ◆ SA/V increased by flattened body shapes and sub-divided structures e.g. exchange surfaces which aid passive and active transport.
- ◆ Exchange surfaces have other special features which aid passive and active transport in addition to their large surface area. They are thin, well supplied with blood vessels, and exposed to the external environment.
- ◆ Gas exchange surfaces must be ventilated to continually replace the external medium in order to maintain the diffusion gradients between it and the blood.
- ◆ Protozoa are single celled organisms with a large SA/V ratio, which is sufficient for gas exchange and internal transport to be by diffusion. Oxygen is absorbed and carbon dioxide eliminated.

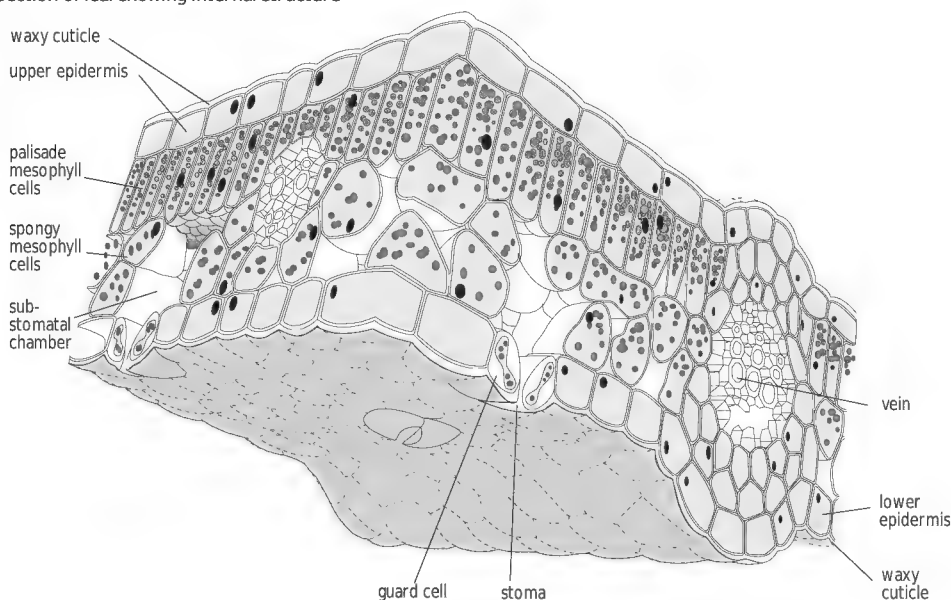


Gas exchange in flowering plants

Gas exchange occurs in flowering plants wherever living plant cells are exposed to the external medium. Most of the plant surface is protected by an almost impermeable waxy cuticle, so gas exchange in aerial parts occurs via special openings, the **stomata**. Woody plant stems are protected by layers of impermeable dead tissue (the bark) and the stomata are replaced by openings (lenticels) full of loosely packed dead cells which permit gaseous exchange. It should not be forgotten that the tips of roots are provided with a large exchange surface composed of **root hair cells**, across which gaseous exchange occurs between the root and the soil air and water film.

The main organ for gaseous exchange is the leaf.

Section of leaf showing internal structure



A typical mesophyte leaf adapted to average water supplies, as opposed to xerophyte (dry adapted) and hydrophyte (wet adapted) leaves, shows many external and internal adaptations to gaseous exchange. As described above, the one cell thick epidermis is covered by an impermeable waxy cuticle which reduces water loss by evaporation. Stomata may be found on both surfaces, but more occur on the under surface of the leaf, where they are more protected from direct sunlight and air currents. Each stoma (singular) is surrounded by two guard cells which control its opening and closing. Each stoma connects to a sub-stomatal cavity inside the leaf, which in turn connects with an extensive system of inter cellular air spaces in the spongy mesophyll. The spongy mesophyll tissue is made up of relatively large irregular cells with a thin cell wall. The air spaces further connect with air spaces between the palisade mesophyll which is the main photosynthesising layer situated below the upper epidermis. In this way gases can be exchanged by diffusion between the external air and all the cells of the leaf, for respiration and photosynthesis.

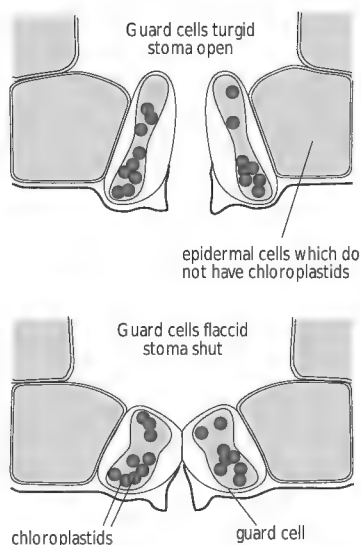
Unit 2B: Exchange, Transport and Reproduction

The rate and direction of exchange depends upon the diffusion gradients of oxygen and carbon dioxide. Remember that photosynthesis occurs during the light periods only but respiration occurs all the time. The air in the air spaces is refreshed by incoming supplies when the stomata are open. There are no 'breathing movements' so the rate of exchange is determined entirely by diffusion gradients. Carbon dioxide and oxygen in the air dissolve in the thin layer of water coating the surface of the spongy and palisade mesophyll cells, then diffuse through the cell wall and the cell membrane.

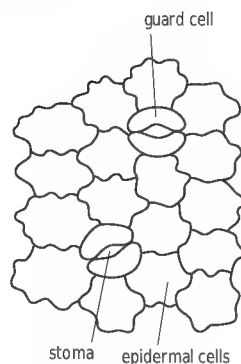
The stomata and their guard cells control the entry and exit of air. The stomata open in the light to permit carbon dioxide to enter by diffusion to supply the photosynthesising palisade mesophyll cells, and to allow oxygen to diffuse out. Whilst open there is a danger of excessive loss of water vapour, and the stomata must strike the correct balance between the needs for gaseous exchange and the control of loss of water vapour (transpiration). A reduction in size of stomata reduces water loss by more than it reduces carbon dioxide uptake. When the rate of respiration exceeds the rate of photosynthesis the diffusion gradients are reversed, and oxygen would diffuse in and carbon dioxide diffuse out, however this mainly occurs in low light intensities when the stomata are closed. In windy conditions the leaves are buffeted and there can be mass flow of air into and out of the leaf, in a form of ventilation.

The guard cells on either side of each stoma are banana shaped and have specially thickened walls. The mechanism by which stomata open and close is still not fully understood, but all theories depend on explanations of the changes in the shape of the guard cells due to changes in their water content or turgidity. When the guard cells are distended with water (turgid), they bend outwards due to the unequal thickening of their walls and the stomata open; when they are not so distended the stomata are closed.

Guard cells are the only epidermal cells to possess chloroplasts and their presence could indicate that photosynthesis is involved in some way. The simple explanation is that the guard cells produce sugars in the light by photosynthesis, and that these sugars increase the concentration of the cell contents so that water is drawn in by osmosis. This increases their turgidity and results in the opening of the stomata. However, this cannot explain the opening and closing of all stomata since many stomata open at night, or at certain times of the day, and changes in the rate of sugar production by photosynthesis would be too slow to account for the rapid opening sometimes seen. It is thought that the mechanism is, at least to some degree, an active process which involves ion transport across the cell membranes of the guard cells. When potassium ions are pumped in the water potential is lowered and water enters by osmosis from the surrounding cells, the cells become turgid and the stomata open. When potassium ions are pumped out the water potential is raised and water leaves by osmosis into the surrounding cells, the guard cells become flaccid and the stomata close.



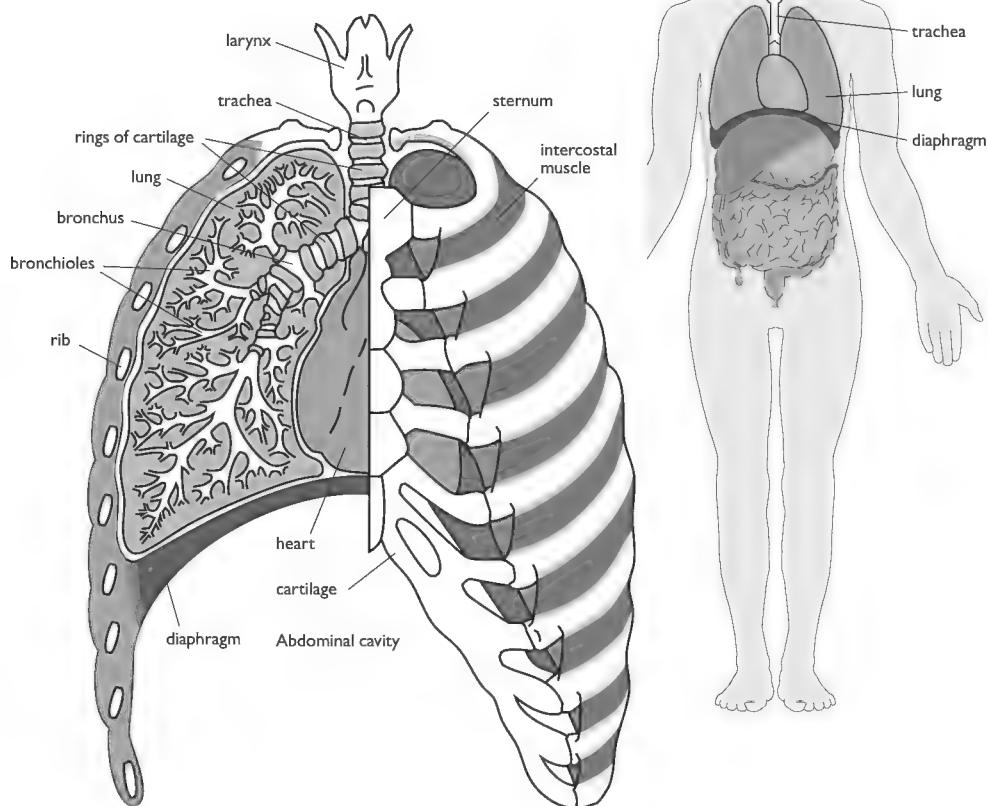
Surface view of leaf epidermis and stomata



GAS EXCHANGE IN HUMANS

The structure of the thorax

The organs of gas exchange in mammals are the lungs which, together with the heart, fill all the available space in the air tight **thorax** (chest cavity). The thorax is bounded by the ribs and the muscular and tendonous sheet known as the **diaphragm**, which separates it from the abdominal cavity.



Air travels through a series of tubes which make up the respiratory system, having first been warmed and moistened in the nasal cavity (if the mouth is shut). The **trachea, bronchi and bronchioles** form a system of branching air tubes referred to as the 'bronchial tree'. The wall of the trachea and bronchi are composed of four layers. These are the inner mucous membrane or **epithelial** layer, a layer consisting of connective tissue, elastic fibres and mucous glands, a layer of **smooth muscle** and **cartilage**, and a tough outer coat of **connective tissue**. Bronchioles differ in that they have less cartilage and do not have mucous glands.

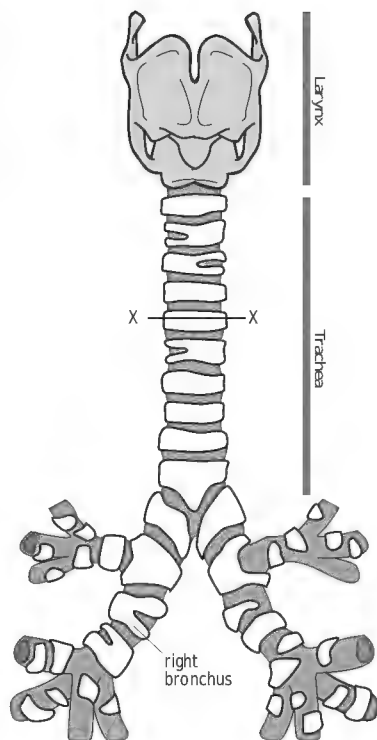
Cartilage supports the trachea and bronchi and prevents their collapse when the internal pressure drops, or when the neck is twisted. In the trachea the cartilage forms C-shaped rings which are arranged so that the open ends of the C are at the back of the tube, facing towards the spine. Between the ends of the Cs at the posterior (back) of the trachea, smooth muscle completes the tube. The incomplete nature of these 'rings' of cartilage allow a degree of compression as a result of the expansion of the oesophagus when swallowing food. In the bronchi the cartilage does not form rings but instead forms plates within the smooth muscle layer to strengthen the tubes.

Involuntary (smooth) muscle found in the trachea, bronchi and bronchioles also helps maintain the shape of the tubes and prevent collapse of the airways. The smooth muscle receives nerve impulses from the autonomic nervous system, and hormones such as adrenaline, which can regulate the diameter of the tubes. This is significant in diseases like asthma and anaphylaxis (allergic shock) where constriction of the bronchioles occurs restricting air flow.

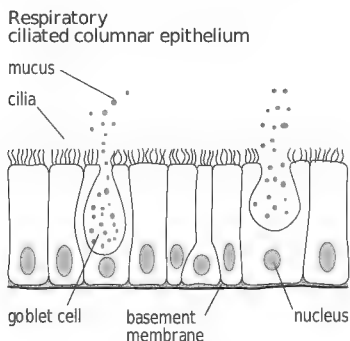
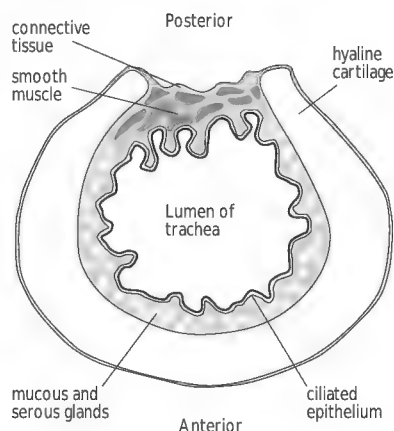
Epithelium lining the trachea, bronchi and bronchioles is known as the mucous membrane, and consists of **ciliated columnar epithelium**. This is composed of: ciliated cells and goblet cells. At the very end of the bronchioles, close to the alveoli no goblet cells are found, only ciliated cells.

Ciliated epithelial cells have a protective function as they work in a co-ordinated fashion sweeping the mucous coat of the air passages (which contains small inhaled particles such as dust towards the back of the throat and mouth, where they can be swallowed or removed by the cough reflex. This prevents such particles from entering the alveoli and interfering with gaseous exchange. Goblet cells are found amongst the ciliated cells in the trachea and bronchi and secrete mucus within the respiratory tract. The layer of mucus which lines the airways traps dust and bacteria. It may also play a role in humidifying inhaled air.

The lungs are surrounded by double pleural membranes which enclose a fluid filled pleural cavity. These lubricate any movements of the lungs against the inside wall of the thorax, and prevent the lungs collapsing under their own elasticity. If air enters the pleural cavity, either as a result of an external penetration or by alveoli bursting outwards, the lungs do collapse.



Section X - X

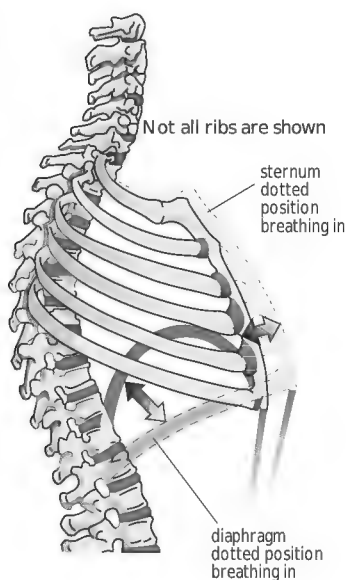


The mechanism of ventilation

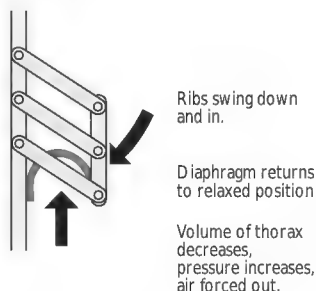
Ventilation in mammals is achieved by the breathing movements of the **intercostal muscles** of the ribs and the muscular **diaphragm** which are controlled by the autonomic and voluntary nervous systems.

During **inspiration** (breathing in) the external intercostal muscles contract pulling the ribs upwards and outwards. At the same time the diaphragm contracts, moving downwards. Both movements increase the volume of the thorax, reducing the pressure in the thorax below atmospheric pressure causing air to enter, inflating the lungs. At rest **expiration** (breathing out) does not involve active muscle contractions, but depends upon the elasticity of the tissues of the lungs and thorax. The intercostal muscles relax, allowing the rib cage to move downwards and inwards, and the diaphragm relaxes and regains its domed shape. The volume of the thorax is reduced, pressure increased and air forced out of the lungs. During forced breathing, for example as a result of exercise or in speech, expiration is active, with the internal intercostal muscles and abdominal muscles contracting to increase the pressure within the thorax.

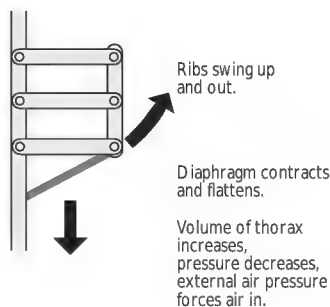
Breathing movements thus result in certain volumes of air passing into and out of the lungs.



Muscles Relaxed



Muscles Contracted



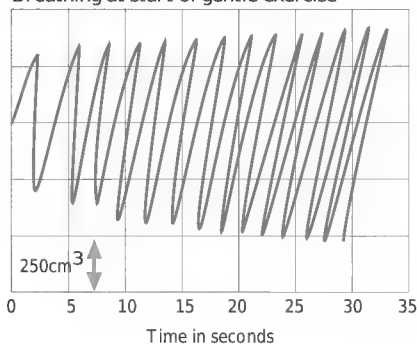
How breathing is controlled

Normally, respiratory movements are involuntary, being controlled by rhythmic discharges of nerve impulses from the respiratory control centres in the **medulla** region of the brain. These impulses travel down the **phrenic nerves** to the diaphragm, and down the **intercostal nerves** to the external intercostal muscles causing them to contract and bring about inspiration. When the alveoli are stretched at the end of inspiration, stretch receptors in the bronchioles send impulses to the **inspiratory control centre** in the medulla to inhibit it and the diaphragm and external intercostal muscles are caused to relax. This leads to expiration. Normally, expiration is passive but it may be assisted by nerve impulses originating in the **expiratory control centre** in the medulla which cause the internal intercostal muscles to contract pulling the ribs in and downwards.

The inspiratory control centre and expiratory control centres are antagonistic to each other, each inhibiting the activity of the other so that neither can operate at the same time. The two centres are responsible for maintaining the basic rhythm of breathing.

The rate of respiration is dependent mainly upon the carbon dioxide concentration of the blood. Any increase in carbon dioxide levels is detected by sensory receptors (chemoreceptors) located in the aorta and carotid arteries which inform the medulla of the need to increase the breathing rate. Carbon dioxide also has a direct effect on the respiratory centres of the medulla. These sensory messages are backed up by other receptors which inform the medulla of increases in temperature and decreases in oxygen levels.

Breathing at start of gentle exercise



Tidal volume

This is the volume of air breathed in and out in a single breathing cycle. During normal quiet breathing at rest, a healthy, active mature male of average height would have a tidal volume of about 500 cm^3 . Of this 500 cm^3 , about 350 cm^3 reaches the alveoli where it mixes with the **stationary air** which is not moved in tidal breathing at rest, and where gaseous exchange occurs. The remaining 150 cm^3 fills the pharynx, larynx, trachea, bronchi, and bronchioles, which compared to the alveoli are poorly supplied with blood capillaries, so that very little, if any, gaseous exchange occurs here. This space where no gaseous exchange occurs is known as the anatomical **dead space**, and the air that occupies it as the **dead air volume**.

By breathing in as deeply as possible an extra volume of air, in addition to the tidal volume and the stationary air, can be taken into the lungs. This is the **inspiratory reserve volume** and can be up to 2000 cm^3 . By breathing out as forcibly as possible after returning to normal breathing, it is possible to expel some of the stationary air in addition to the tidal volume. This is known as the **expiratory reserve volume** and can be up to 1500 cm^3 . However the lungs cannot be emptied entirely, otherwise they would collapse, and this remaining air is known as the **residual volume** which can be up to 1500 cm^3 .

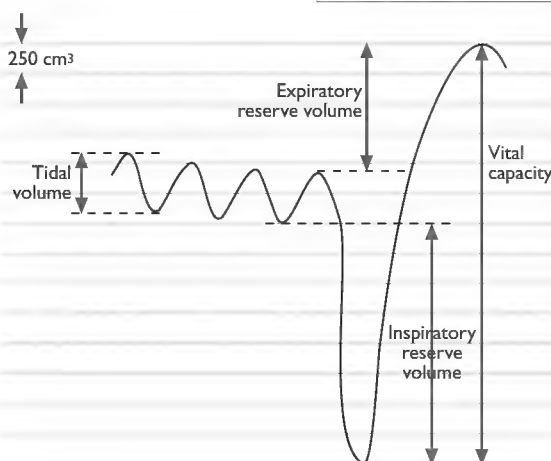
Vital capacity

This is the sum of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume. The vital capacity represents the maximum total amount of air that can be moved into and out of the lungs by one inhalation and one exhalation, and is about 3000 cm^3 - 4000 cm^3 in the adult male.

These volumes and the lung capacities vary considerably between individuals. They are generally smaller in females than in males, due to smaller average body size in females, and correlate closely with body size, height and surface area up to age 25. Smoking and associated lung diseases can considerably reduce lung volumes and capacities.

CHECKPOINT SUMMARY

- The thorax is defined by the rib cage and its associated intercostal muscles, and the diaphragm.
- A system of air tubes; the trachea, bronchi and bronchioles form the 'bronchial tree' supplying the air sacs (alveoli) of the lungs.
- Inspiration occurs when the intercostal muscles contract raising the rib cage, and the diaphragm contracts and flattens, increasing the volume and decreasing the pressure within the thorax below that of the external air pressure, resulting in the entry of air.
- The pleural fluid between the two pleural membranes lubricate the movement, and keep the lungs inflated against the wall of the thorax. Surfactants secreted inside the alveoli lower their surface tension and decrease their risk of collapse.
- Expiration at rest is passive, as the intercostal muscles and the diaphragm relax and the tissues of the thorax recoil as a result of their elasticity.
- The volume of air that is breathed during a complete breathing cycle of one breath in and one out is known as the tidal volume. Breathing becomes deeper as well as more rapid with exercise, and expiration becomes active.
- The vital capacity is the total amount of air that can be breathed with the deepest possible breath in and the deepest possible breath out.
- Breathing is controlled by the respiratory centre in the brain which receives stimuli from chemoreceptors in the blood vessels detecting the level of carbon dioxide, oxygen and pH in the blood, and stretch receptors in the lungs.



This trace does not show the total lung volume and residual volume, which are not easily measured. With increasing age the residual volume increases from about 20% of the total lung volume to more than 30%.

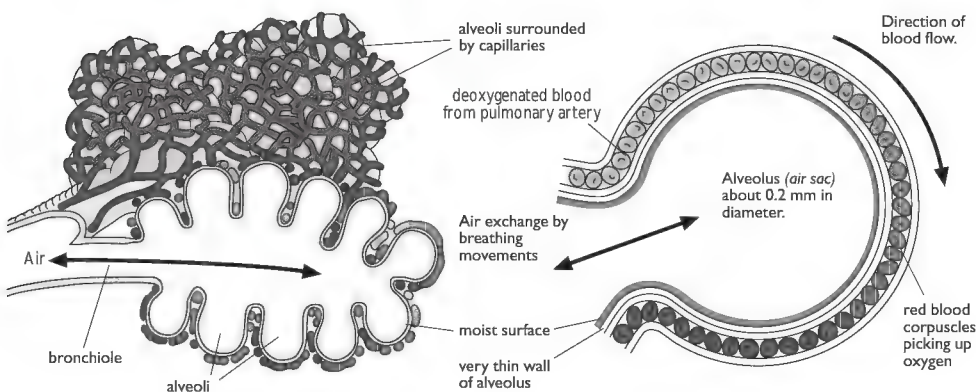
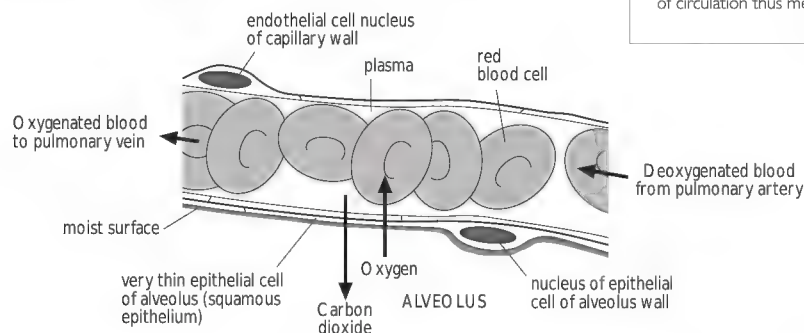
Alveoli

Alveoli or air sacs make up the mass of the lungs. The ends of the bronchioles terminate in alveolar ducts which lead to the alveoli where gas exchange occurs. Although each alveolus is very small, the large numbers of alveoli provide an enormous surface area for gas exchange.

Each alveolus is surrounded by a net of capillaries which together form the **alveolar-capillary complex**. As this name suggests, the endothelium of the capillaries is attached to the thin squamous epithelium of the alveolus via a shared basal membrane. The air inside the alveolus and the blood in the capillaries is thus separated by a distance of just the thickness of two layers of cells. This is one feature that helps rapid diffusion of oxygen from alveolus to blood and carbon dioxide from blood to alveolus. Other features include the large surface area already mentioned, and the steep diffusion gradients which are maintained between the blood and the alveolus due to the constant movement of the blood and the constant ventilation of the lungs.

The presence of a phospholipid material called **pulmonary surfactant** acts like a detergent, reducing the surface tension of fluids at the alveolar surface ensures that the tiny air sacs do not collapse.

Gas exchange alveolus/capillary



◆ CHECKPOINT SUMMARY

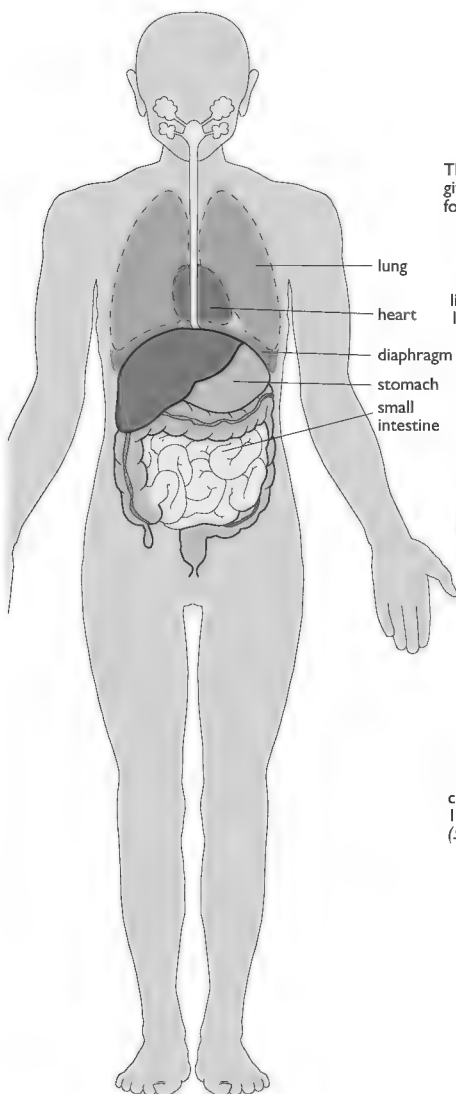
- ◆ Gas exchange occurs over large surface area of alveoli which is a product of their relatively small size and large number.
- ◆ Diffusion gradients of oxygen and carbon dioxide dependent upon partial pressures of gases on either side of diffusion surface.
- ◆ Diffusion surface composed of thin squamous epithelium ridged around the sandwiched capillaries, which further increases their surface area.
- ◆ Air in alveoli remains fairly constant in composition independent of breathing cycle.
- ◆ Surface water an inevitable consequence of a permeable surface exposed to air decreases diffusion of oxygen more than the diffusion of carbon dioxide.
- ◆ Diffusion gradients maintained by circulating blood and ventilation of lungs.
- ◆ As demand for oxygen increases so does steepness of diffusion gradients and speed of circulation thus meeting extra demand.

DIGESTION AND ABSORPTION

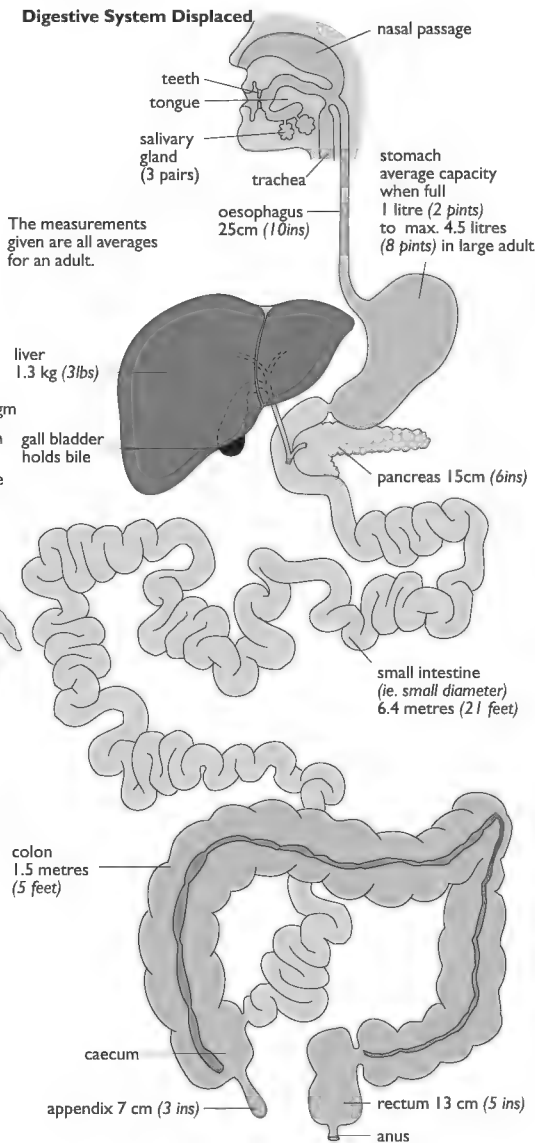
The structure of the alimentary canal

In humans, as in all other mammals, food is processed within a highly specialised alimentary canal or gut. Here the processes of digestion and absorption occur.

Digestive System in Place



Digestive System Displaced



Digestion is the process whereby large complex organic molecules are broken down into smaller, soluble molecules by enzyme catalysed hydrolysis.

Absorption is the process whereby the simple, soluble products of digestion, along with water and inorganic mineral ions and vitamins move through the wall of the gut and enter the blood and lymphatic systems for distribution around the body.

The alimentary canal forms a long, continuous tube from mouth to anus but is divided into distinct regions with differences in structure and function. A striking feature of most regions are the modifications, at both gross and microscopic level, to create a very large surface area for digestion and absorption to occur.

Food is ingested via the mouth where both **physical** and **chemical digestion** (by enzymes) begins. Within the mouth the food is moved between a range of specialised teeth by the muscular tongue and the cheeks. Molar teeth are adapted to grind the food, incisors to cut the food and canines to piece and tear the food. As food is chewed it is mixed with saliva from the three pairs of salivary glands which contains the enzyme salivary amylase. This physical processing in the mouth has several important functions: it breaks the food into smaller pieces to make swallowing easier; it mixes the food with saliva to lubricate the food and again aid swallowing; it increases the surface area of the food for the action of enzymes and brings the food into contact with salivary amylase, the first of the carbohydrase enzymes. This begins the digestion of starch to maltose.

Movement of food along the gut.

Food is not moved through the gut by the forces of gravity: it is possible to swallow food and maintain normal movement of food through the gut whilst standing on your head! Instead the movement relies on smooth muscle in the muscularis externa (see below) of the gut wall. The muscles are controlled by the nerves of the autonomic nervous system (the branch of the nervous system which controls the basic processes of the body) which run through them. Along with hormonal signals these regulate the speed of movement of food through the gut and also allow the gut to move the food around as it goes.

The movement of food along the gut from the oesophagus towards the anus is known as **peristalsis**. Moving the food around within a region of the gut to allow it to be mixed with enzymes and other secretions hence aiding digestion and absorption is known as **segmentation**.

Peristalsis relies on two layers of muscle within the gut wall: the inner circular muscles and the outer longitudinal muscles contracting against the material in the gut lumen. Although the process is really continuous, an individual wave can be considered in two stages. Firstly contraction of the longitudinal muscle and relaxation of the circular muscle leads to a widening of the lumen and shortening of the section of gut. Secondly relaxation of the longitudinal muscles and contraction of the circular muscles behind a bolus of food leads to an elongation of the gut section and a constriction of the gut lumen. Between them these moves have the effect of squeezing the gut contents together and then pushing them along the gut. (A similar effect is achieved in trying to move toothpaste up a tube. When food is present 10-12 such waves occur in the duodenum each minute with a smaller number (3-4) in the colon.

The histology of the ileum (small intestine) wall

The ileum, the longest part of the small intestine is where the majority of digestion and absorption of food (proteins, fats and carbohydrates) takes place. In view of this the wall layers of this region of the gut are highly specialised for these functions.

In the ileum, as in all parts of the alimentary canal, the wall of the gut is composed of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa.

Mucosa. This innermost layer lines the gut lumen consists of epithelial cells overlying connective tissue and a thin layer of muscle. The epithelial cells have a range of secretory and absorptive functions in different gut regions. In all regions the mucosa contains numerous lymphocytes (white cells) to help protect from harmful foreign substances.

Submucosa. A layer of dense connective tissue containing blood vessels, lymphatic vessels and nerve fibres. The role of the capillaries and the lymphatics is to absorb the products of digestion and soluble nutrients and transport them away from the gut.

Muscularis externa. Consists in most regions of an outer longitudinal muscle layer and an inner circular muscle layer. Together these aid movement of food within and through the gut by peristalsis. Nerve fibres run through the muscle layers to control the movements of the muscles.

Serosa. An outer layer of squamous epithelial cells forming a membrane which contributes to the support of the gut in the abdominal cavity.

The submucosa and mucosa layers of the ileum form folds which increase the surface area for the absorption of food and slow the movement of food through this region. The mucosa forms finger like villi (0.5-1mm in height) which greatly increase the surface area.

Each villus contains blood capillaries to absorb small molecules such as glucose, and a lymphatic capillary (the lacteal) to absorb fats. A thin muscle layer helps the villus to move and hence come into contact with digested food molecules.

The cells of the villus are also specialised. Most bear surface projections called microvilli further increasing the surface area for absorption. Some of these microvilli have digestive enzymes attached to the cell membrane. Goblet cells on the villi secrete mucus to aid lubrication of food.

Cells found in the crypts of Lieberkuhn between the villi secrete a fluid containing mucus, salts and antibacterial substances. Some enzymes are released by the breakdown of cells at the tips of the villi.

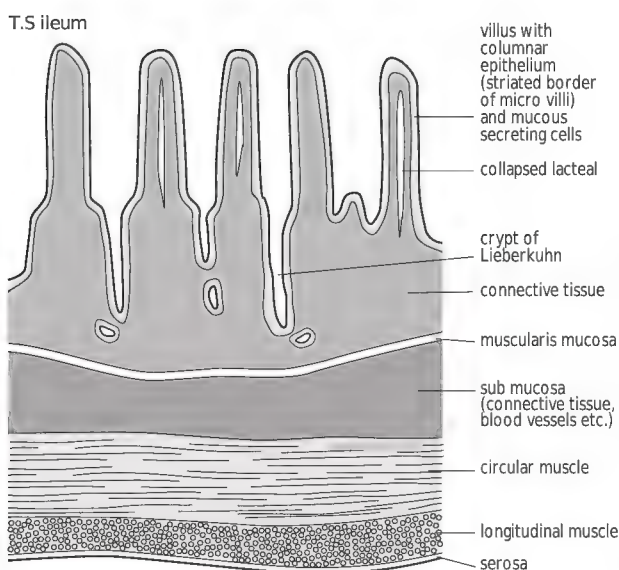
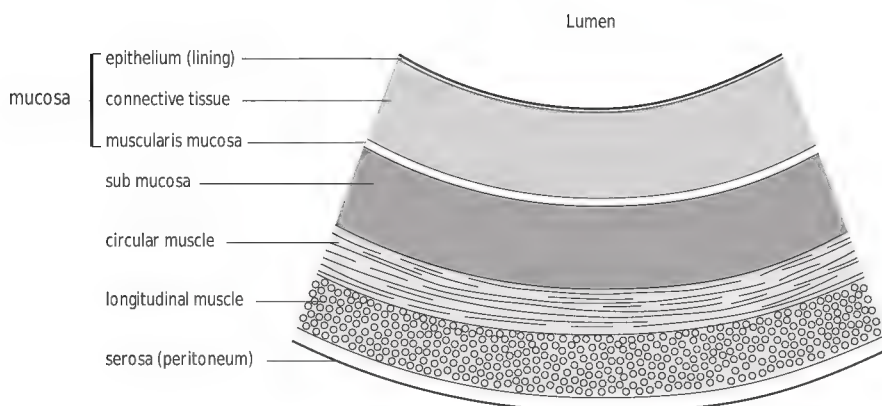
Mucus and an alkaline fluid to neutralise the acid chyme of the stomach are secreted in the duodenum by the Brunner's glands located in the sub mucosa.

The muscularis externa in this region is responsible for peristalsis and segmentation as in other gut regions.

◆ CHECKPOINT SUMMARY

- ◆ Food is masticated by the teeth and the tongue to increase the surface area for digestion and to mix it with saliva for ease of swallowing.
- ◆ The smooth muscle moves the food through the gut by autonomic waves of contractions (peristalsis).
- ◆ The main regions of the gut are, the mouth (buccal cavity), oesophagus, stomach, duodenum, ileum, colon, and rectum.
- ◆ From the oesophagus to the rectum the wall of the gut is comprised of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa. These layers are modified in each region in accordance with its function.
- ◆ The oesophagus is lined with stratified epithelium. This is several layers of cells thick and protects underlying structures from damage. Mucous glands secrete mucus to lubricate the food, and thick layer of smooth muscle pushes food down by peristalsis.
- ◆ The stomach wall is folded and contains gastric glands which open into gastric pits. There are three types of secretory cells in these glands: mucus secreting cells, oxyntic cells secreting hydrochloric acid and chief cells secreting pepsinogen (later converted to the pepsin). Smooth muscle mixes and moves food into the small intestine.

General plan of tissues of alimentary canal



◆ **CHECKPOINT SUMMARY**

- ◆ The small intestine submucosa and mucosa form folds and villi which increase the surface area for the absorption of food and slow the movement of food.
- ◆ Goblet cells secrete mucus whilst Paneth cells found in the crypts of Lieberkuhn between the villi secrete antibacterial lysosome.
- ◆ Each villus contains blood capillaries to absorb all nutrients, and a lymphatic capillary (the lacteal) to absorb fats. The cells of the villus bear surface projections called microvilli.
- ◆ Brunners glands are restricted to the duodenum and secrete mucus and an alkaline fluid to neutralise the acid chyme.
- ◆ The large intestine consists of the colon where most water is absorbed, the caecum and appendix which are much reduced (vestigial) in humans, and the rectum into which faeces move before defaecation.

The digestion and absorption of carbohydrates.

Up to 70% of the human diet consists of carbohydrates. A small proportion of these are taken as simple sugars (e.g. fructose in fruit) which do not require digestion, but the majority is in the form of starch, a large complex polysaccharide requiring digestion by enzymes. Non-starch polysaccharides, mainly cellulose, are also eaten but provide no nutrients for humans since they cannot be digested, but act as bulk (roughage) which provides resistance for the contraction of the muscular walls in peristalsis.

Carbohydrate digestion begins in the mouth where the enzyme salivary amylase begins to hydrolyse the 1-4 α -glycosidic bonds and digests starch to maltose (a disaccharide). When food reaches the stomach the action of this enzyme persists for a while but is soon inhibited by the acid conditions.

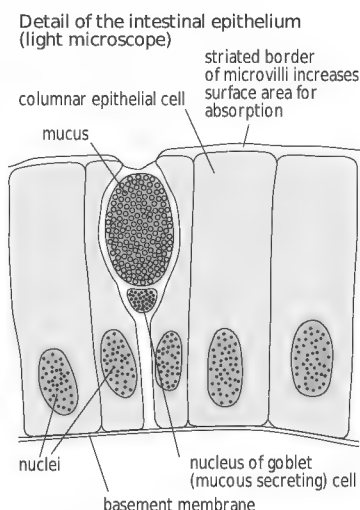
The bulk of carbohydrate digestion occurs in the small intestine. Pancreatic amylase, produced by the pancreas and secreted into the duodenum continues the digestion of starch to maltose. The alkaline salts in the pancreatic juice provide the optimum pH (8.5) for pancreatic amylase to function. The release of pancreatic juice and pancreatic enzymes is stimulated by the hormones cholecystokinin (CCK) and secretin which are released in response to the presence of food in the gut.

Maltose is digested to glucose by the enzyme maltase which is embedded in the membrane of the microvilli of the mucosa. The glucose is then taken into the epithelial cells of the mucosa by active transport and passed into the bloodstream by facilitated diffusion.

In addition to maltase other disaccharide digesting enzymes are found on the surface of the microvilli. Here sucrase breaks down sucrose to form glucose and fructose, and lactase breaks down lactose to form glucose and galactose. Of these monosaccharides glucose and galactose are taken up into the cells by active transport whilst fructose moves in by facilitated diffusion.

All monosaccharides pass through the single layer of epithelium and into the blood capillaries to be transported to the liver.

The table below shows the sites of production, sites of action and function of some of the main groups of enzymes involved in carbohydrate digestion.



Name of enzyme	Site of production	Site of action	Function
Salivary Amylase	Salivary glands of mouth	Mouth	Digest starch to maltose
Pancreatic amylase	Pancreas	Lumen of small intestine	Digest starch to maltose
Sucrase	Epithelial cells of ileum	Ileum	Digest sucrose to glucose and fructose
Lactase	Epithelial cells of ileum	Ileum	Digest lactose to glucose and galactose
Maltase	Epithelial cells of ileum	Ileum	Digest maltose to glucose

2B.2

Transport Systems

Content

Transport systems

- The need for transport systems in relation to size and surface area to volume ratio
- The concept of mass flow and the movement of molecules within organisms

Transport in flowering plants

- The structure of the vascular tissues; xylem tissue composed of vessels, tracheids, fibres and xylem parenchyma
- The role of vessels in relation to transport
- ▼ Phloem tissue composed of sieve tube elements, companion cells, phloem fibres and phloem parenchyma
- ▼ The role of sieve tube elements and companion cells in relation to transport

Movement of water

- The structure of a dicotyledonous root
- The uptake of water and its transport across the root to the xylem
- ▼ The way in which water is moved through the plant; the apoplast, symplast and vacuolar pathways; the role of the endodermis
- ▼ The structure of vessels in relation to the cohesive and adhesive forces of water and their contribution to the movement of water through the plant
- ▼ The functioning and roles of the transpiration stream; roles of stomata
- ▼ The effect of different environmental conditions on the transpiration stream

Movement of nutrients

- The roles of diffusion and active transport in the uptake of mineral ions by roots
- The transport of mineral ions through the plant
- ▼ The translocation of organic solutes
- ▼ The difference between the transport of water and organic solutes
- ▼ The structure and arrangement of sieve tube elements, companion cells and transfer cells in relation to the movement of organic solutes.

continued....

Transport in mammals

- ▼ The functions of the circulatory system in the transport of respiratory gases, metabolites, metabolic wastes and hormones.
- ▼ The double circulatory system.
- ▼ The structure of the mammalian heart and coronary circulation.
- ▼ The cardiac cycle; myogenic stimulation; coordination of the cardiac cycle.
- ▼ The structure and roles of arteries, veins and capillaries

Blood and body fluids

- ▼ The composition of blood as plasma and blood cells, including erythrocytes and leucocytes (neutrophils, eosinophils, monocytes and lymphocytes).
- ▼ The structure of erythrocytes and their role in transport.
- ▼ The roles of leucocytes in phagocytosis and secretion of antibodies.
- ▼ The transport of oxygen and carbon dioxide.
- ▼ The roles of respiratory pigments (haemoglobin, fetal haemoglobin and myoglobin).
- ▼ Dissociation curves of haemoglobin and the Bohr effect.
- ▼ The interchange of materials between capillaries and tissue fluid, including the formation and reabsorption of tissue fluid.

TRANSPORT SYSTEMS

Unicellular organisms and small multicellular organisms have a large surface area to volume ratio, which means that most cells are close enough to the external medium for diffusion to be sufficient for the exchange and internal transport of substances. For example the uptake of oxygen and nutrients, and the elimination of waste products. Therefore there is no need for specialised transport systems.

The larger a living organism is, the smaller its surface area to volume ratio is likely to be. All large multicellular organisms require a transport system to carry substances from the specialised organs located at the source of their nutrient and oxygen supply to the most remote of their tissues where the materials are being utilised (the sink). In many animals the mass flow of fluid (blood) is achieved by pumping hearts and blood vessels, and in plants with vascular tissue (xylem and phloem) it is achieved by water potential and pressure gradients.

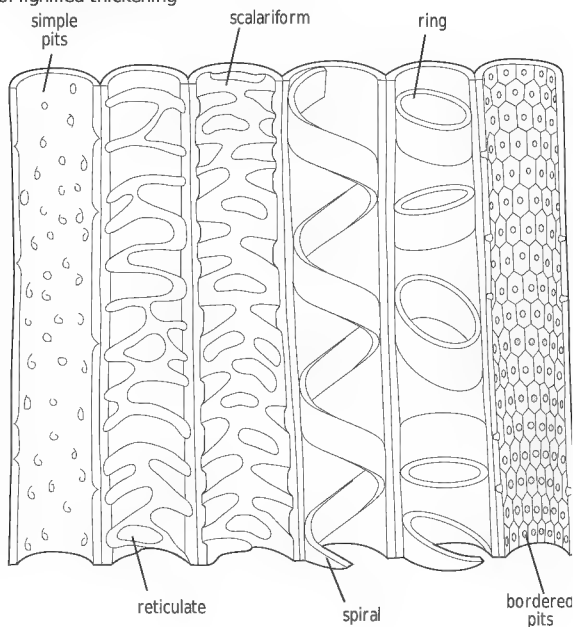
At the interfaces between the mass flow transport fluid and the external environment, and the fluid and the tissues movement of molecules is by diffusion and/or active transport occurs across cell surface membranes.

TRANSPORT IN FLOWERING PLANTS

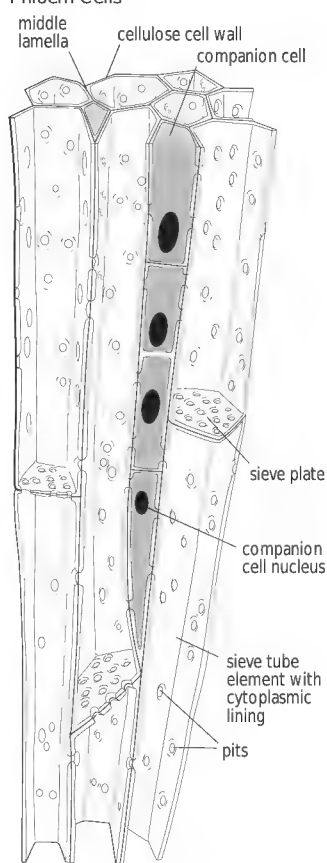
The structure of the vascular tissues

The vascular (transport) tissues in flowering plants are made up of xylem elements (vessels and tracheids) which transport water and inorganic nutrients, and phloem elements (sieve tube elements and companion cells) which transport sugars and other organic substances. Both xylem and phloem tissue also contain fibres (supporting cells) and parenchyma (packing cells).

Xylem vessels showing different types of lignified thickening



Phloem Cells



Xylem vessels have thickened lignified walls and no living contents, and form tubes in which water travels from the roots to the leaves. Lignin is a tough, hard, waterproof substance, and lignified tissue makes up what is commonly known as 'woody tissues' or 'wood'. Lignin is waterproof, and this ensures that the water is restricted to the large clear lumen which is produced as a result of the death of the living contents. The strong lignified walls can also withstand the negative pressures which exist inside the the xylem elements as a result of the upward pull of the transpiration stream. The walls are pitted to allow for passage of water through the lignified walls between neighbouring elements of the xylem. In vessels most of the cross walls that were originally present between vessel elements break down, leaving long clear, uninterrupted tubes (up to a metre or more long) with diameters ranging from 20 -600 μm , presenting much less resistance to water movement.

Phloem is made up of living sieve tube elements and their companion cells. Sieve tube elements are elongated cells 150 - 1000 μm long with a diameter of 10 - 50 μm which lose their nucleus in the process of maturation, and whose end walls develop into sieve plates with numerous pores. This allows for the passage of materials up and down the long columns of sieve tube elements which run between the roots and the leaves in the vascular tissue. Each sieve tube element is associated with up to six companion cells along its length. These companion cells do have nuclei in their dense cytoplasm, and are thought to exert some regulating action on the sieve tube elements.

◆ CHECKPOINT SUMMARY

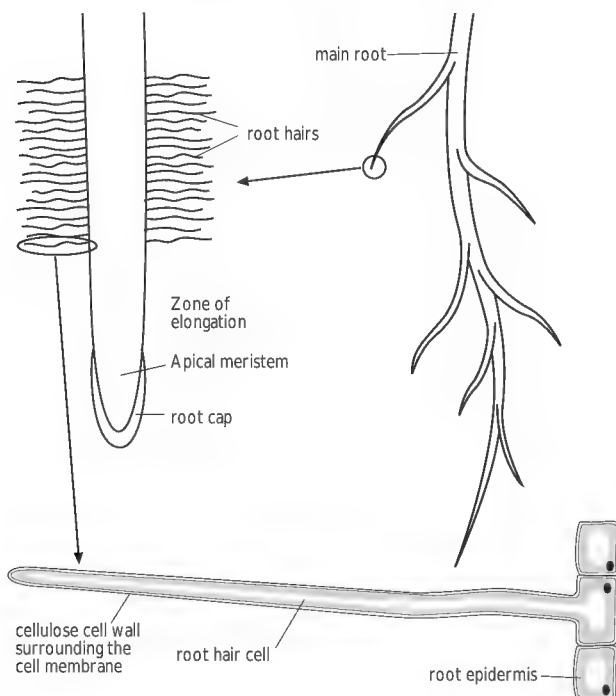
- ◆ Surface area increases with increasing size but the surface area to volume ratio decreases.
- ◆ SA/V increased by flattened body shapes and structures.
- ◆ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ◆ Discussions of development of transport systems also involve level of complexity of organism.
- ◆ Development of transport systems involve the mass flow of fluids.
- ◆ Development of transport systems involve development of specialised exchange surfaces with large surface areas.
- ◆ Diffusion still important in all exchanges, but not in transport throughout volume of organism.
- ◆ Xylem tissue is composed of vessels, tracheids, fibres and xylem parenchyma.
- ◆ Vessels have lignified walls with pits, empty lumen, reduction of cross walls, diameters range from 20 - 600 μm , and they can be up to a metre long.
- ◆ These elongated empty elements are well adapted to the rapid transport of water; offering little resistance to flow of water in transpiration stream.
- ◆ Xylem tracheids are very similar to vessels except they have pitted cross walls at regular intervals, and they are smaller in cross section. They are also used in the transport of water.
- ◆ Fibres are elongated narrow lignified elements for support.
- ◆ Xylem parenchyma are living cells which occur in the medullary rays and act as food storage regions.
- ◆ Phloem tissue is composed of sieve tube elements, companion cells, phloem fibres and phloem parenchyma.
- ◆ Sieve tube element have cellulose cell walls, sieve tube plates at regular intervals, and living contents but no nuclei. They are involved in the transport of organic compounds, mainly sucrose.
- ◆ The companion cells do have nuclei and play some role in the functioning of the sieve tube elements.
- ◆ Phloem fibres and phloem parenchyma are found associated with the sieve tubes and companion cells in the vascular bundle.

MOVEMENT OF WATER

Root structure

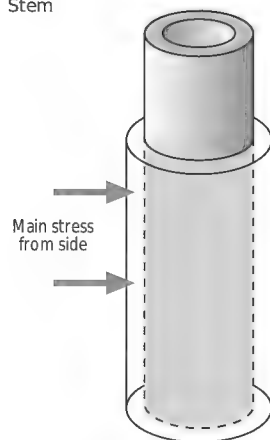
The source of water and inorganic nutrients for plants is the soil. Plant roots are specialised to provide a large surface area for the absorption of water and inorganic ions whilst securing the plant in the ground and protecting it from the pulling forces exerted as a result of the action of the wind on the stem and leaves.

The uptake of water and ions occurs only at the root hairs, situated just behind the root tips of newly formed root branches. The hairs are extensions of single, thin walled, epidermal cells. Individually they have a large surface area to volume ratio, and collectively they create a huge surface area for exchanges with the soil.



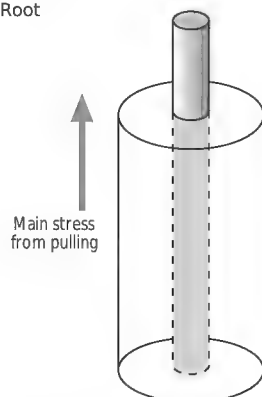
The internal anatomy of roots differs from that of stems in a number of respects, notably the arrangement and position of the vascular tissues (xylem and phloem). As xylem has an important structural and supporting role, its distribution in the root, stems and leaves reflects the mechanical stresses endured by the particular region. In dicotyledonous plant stems, it is arranged in a cylindrical fashion, giving resistance to bending forces created by the wind. In the roots it is concentrated in the centre, resisting pulling forces. (It is interesting to note that aquatic flowering plant species adapted to growing in flowing currents have the stem vascular tissue in the centre, as this best resists the pulling strain of the currents.) In the leaf veins, it ensures that the leaf is supported in a position favourable to photosynthesis.

Stem



Vascular tissue forms a strengthened cylinder which resists bending

Root



Vascular tissue forms a strengthened inner core which resists pulling action

Another difference between the anatomy of roots and stems is that the root has a cylinder of specialised cells, the **endodermis**, enclosing the central vascular tissues. This had an important role in transport, as you will see later, and crucial to that role is the ring of waterproof thickening (Casparian strip) which seals its cell walls and ensure that all materials transported from the soil solution to the xylem pass through the cytoplasm of the endodermal cells.

The uptake of water and its transport across the root to the xylem

Water entering the root may travel along three pathways.

The **apoplastic** pathway involves water moving through the porous cellulose walls of the cells of the root cortex. It is pulled in by the transpiration stream (see below). However, the waterproof Casparian strip gives the endodermis control over this process, effectively blocking the apoplastic route and ensuring that all water passes through the cytoplasm of the living passage cells of the endodermis.

The **symplastic** pathway involves water moving through the cell membranes and cytoplasm of the cells of the cortex of the root down a water potential gradient by osmosis.

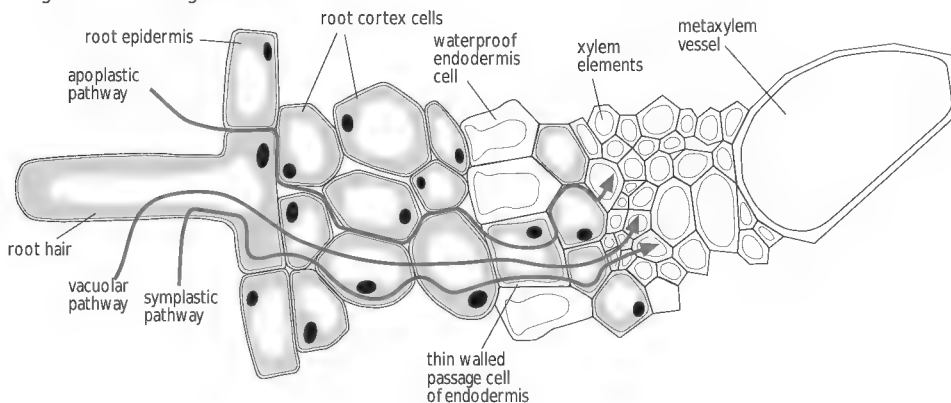
The **vacuolar** pathway involves water moving through the cell membranes and cytoplasm of the cells of the cortex of the root, and through the vacuolar membranes and vacuoles, down a water potential gradient by osmosis.

The apoplastic pathway offers the least resistance to the movement of water, as the water does not have to pass through any living membranes or cytoplasm (except at the endodermis), and most water passes across the root this way. The symplastic and vacuolar pathways are routes of high resistance as the water must pass through the many membranes and the cytoplasm, and are mainly involved in the supply of water to individual root cortex cells from the main flow of water streaming across into the xylem.

◆ CHECKPOINT SUMMARY

- ◆ Roots provide anchorage, and take up water and inorganic ions from the soil solution.
- ◆ As roots have to resist predominately pulling strains, the vascular (transport) tissue containing the phloem and woody xylem is found in the centre.
- ◆ Uptake of water and ions from the soil solution is via the root hairs which present a large total surface area for uptake.
- ◆ The endodermis is a cylinder surrounding the central vascular tissue, it is composed of cells the walls of which become impregnated with impermeable waterproof suberin and eventually die, except for living passage cells.
- ◆ Water can enter and travel through the root along three pathways; the apoplast, symplast and vacuolar pathways.
- ◆ The endodermis acts as a barrier to prevent the loss of accumulated ions in the root, and to force the water and ions being taken up to pass through the contents of living cells at least once in its passage across the root.
- ◆ The apoplast pathway is in the porous cellulose cell walls, and the water is pulled directly through by the transpiration stream, and it only passes through a living membrane in the passage cells of the endodermis.
- ◆ The symplast pathway involves water entering into the cytoplasm of a root hair cell and passing in the cytoplasm from cell to cell via the plasmodesmata.
- ◆ The vacuolar pathway involves water passing down a water potential gradient from vacuole to vacuole, the pathway of greatest resistance.

Passage of water through the root



Pathway and mechanism of water transport from roots to leaves

Transpiration is the loss of water from the leaves by evaporation. Although a tiny amount of water may be lost directly through the 'waterproof' cuticle of the upper and lower epidermis of the leaves, virtually all of it occurs through the stomata of the leaves when they are open. Transpiration is an unavoidable consequence of gaseous exchange. As stomata open in the light to take in carbon dioxide for photosynthesis, so water vapour escapes. However, transpiration does have some beneficial effects, it provides the force for the mass flow (transpiration stream) bringing water and mineral ions to the leaves from the roots. It also exerts a cooling effect. Under very hot conditions, however, when the cooling effect is most required, the stomata tend to close, thus stopping transpiration.

Transpiration provides the main force for water transport from root to leaf. The greater bulk of water is pulled in directly by the transpiration stream, acting through a continuous system of water between the soil solution and the xylem in the porous cellulose cell walls of the cells, the apoplastic pathway.

Water and dissolved solutes move up the stem in the xylem tissue. The generally accepted explanation of the mechanism for the upward transport of water is that known as the **cohesion-tension mechanism**. It is based on purely physical forces and does not involve the activities of living cells. Evaporation through the leaf pores or stomata causes a gradient of water potential across the mesophyll cells of the leaf, and a direct force on the water in the porous cellulose cell walls which causes water to be withdrawn from the xylem. Cohesive forces between water molecules result in a column of water being drawn up the plant in the xylem as the water evaporates from the leaves. This transpiration 'pull' generates a tension which results in the sap being under a negative pressure. It can produce a measurable decrease in stem diameter (and even trunk diameter) when transpiration is high. The strong lignified walls of the xylem vessels withstand this negative pressure which tends to collapse the tubes. The water column is supported and prevented from falling back down under gravity in the xylem elements by adhesion of the water to the smooth lignified walls of the xylem vessels. A continuous water column is necessary for this mechanism, and any breakages caused by storm damage or freezing (which forces air out of solution) can be by-passed via the system of lateral pits in the lignified walls. In woody plants only the most recently formed 'sap wood' functions in water transport, and the remaining 'heartwood' is used as a depository for waste products (but is still important in support).

This mass flow of water carries along dissolved inorganic ions in solutions by 'solvent drag' and contributes to the uptake of inorganic ions from the soil solution by the plant.

Factors affecting transpiration include anything that affects the supply of water to the leaves, and the evaporation of water from the leaves. The main factors are:

Availability of soil water determines the supply of water to the plant. Any factor that decreases the availability of soil water will decrease transpiration, which eventually can lead to the stomata closing and in extreme cases to wilting of the plant.

Relative humidity is a measure of the water vapour content of the air. The diffusion of water vapour out through the stomata of a leaf only occurs when the relative humidity of the surrounding air is lower than that of the internal leaf spaces. The rate of transpiration increases with decreasing relative air humidity. Relative humidity is dependent mainly on temperature, decreasing as temperature increases. A rise of 10°C doubles the steepness of the humidity gradients from leaf to air, thus increasing transpiration.

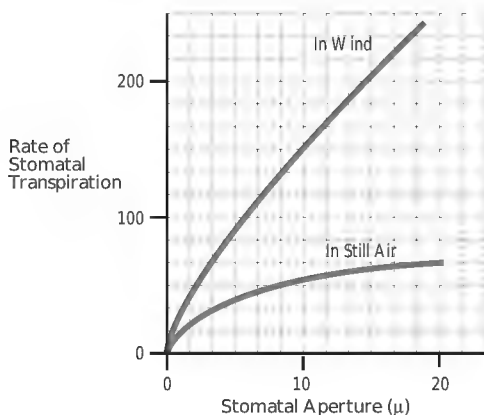
Air movements increase the rate of water loss by transpiration as molecules of water vapour are carried away from the leaf surface reducing the relative humidity of the air that is immediately surrounding it.

Temperature increase provides energy for an increase in evaporation of water from the leaf.

Light intensity exerts its main effect directly on the guard cells surrounding the stomata. These are the only cells on the surface of the leaf which possess chlorophyll, and an increase in light intensity typically results in their daytime opening and a consequent increased transpiration rate. Indirectly it will also raise the temperature of the leaf as its radiant energy is absorbed.

Stomatal number and size vary widely between species, typically being directly correlated with the availability of water. There are usually more stomata on the lower side of leaves. Some plants (e.g. laurel) have stomata only on the lower side. Grasses having vertical leaves have roughly equal numbers on both surfaces. On average there are about 300 per mm² of leaf surface.

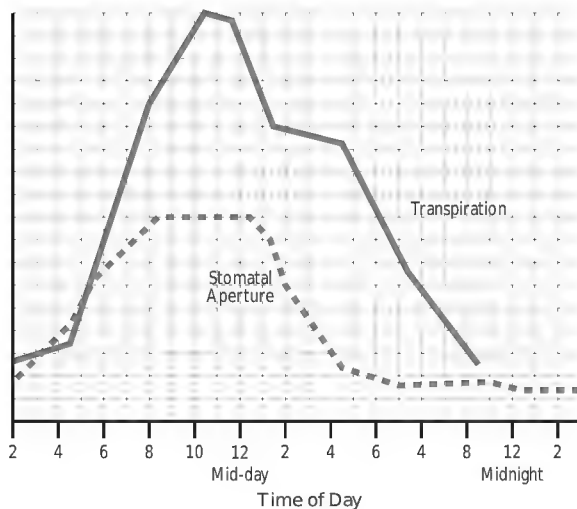
Stomata allow the uptake of carbon dioxide for photosynthesis but at the same time they control the rate of water loss. Changes in stomatal size affect water loss more critically than carbon dioxide gain, for example if the pore size is reduced, the transpiration rate is reduced more than the rate of carbon dioxide uptake.



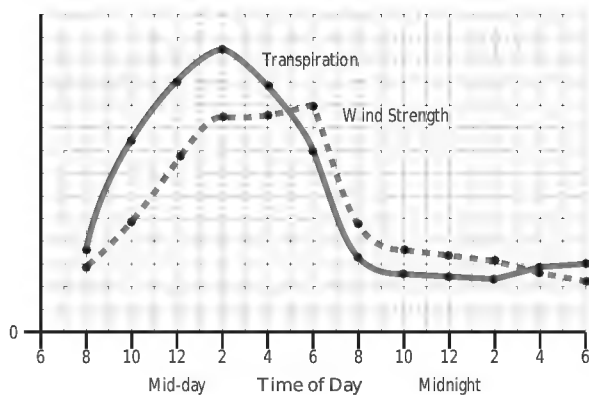
Unit 2B: Exchange, Transport and Reproduction

Factors affecting rate of transpiration over a 24 hour period

1 Stomatal aperture

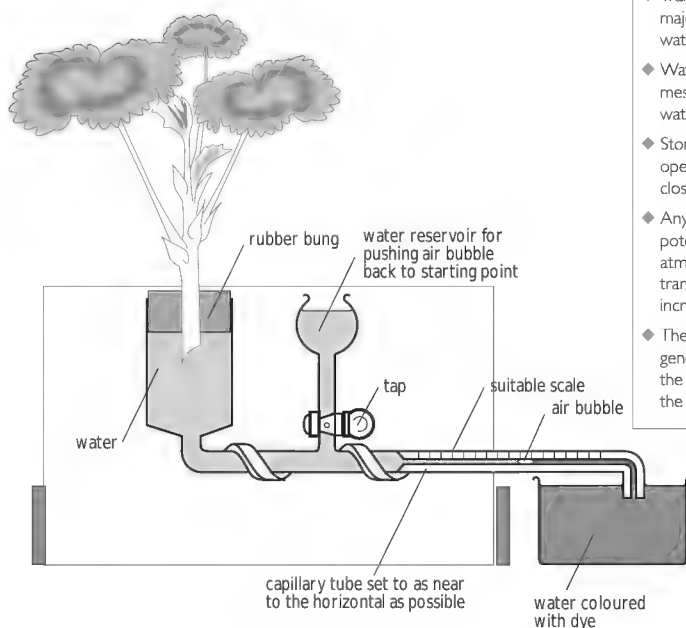


2 Wind strength



Experimental investigation of factors affecting transpiration rate

Investigations of the effect of many of these factors can be carried out using a simple piece of laboratory equipment, the potometer, in which a cut shoot is exposed to different conditions and its water uptake is measured. The rate of water uptake is assumed to be the same as the rate of transpiration, but with a cut shoot the cross sectional area of the cut stem is not as great as the surface area of roots that would normally supply water to that shoot. The transpiration rate from the shoot would therefore be greater if still attached to the rooted plant.

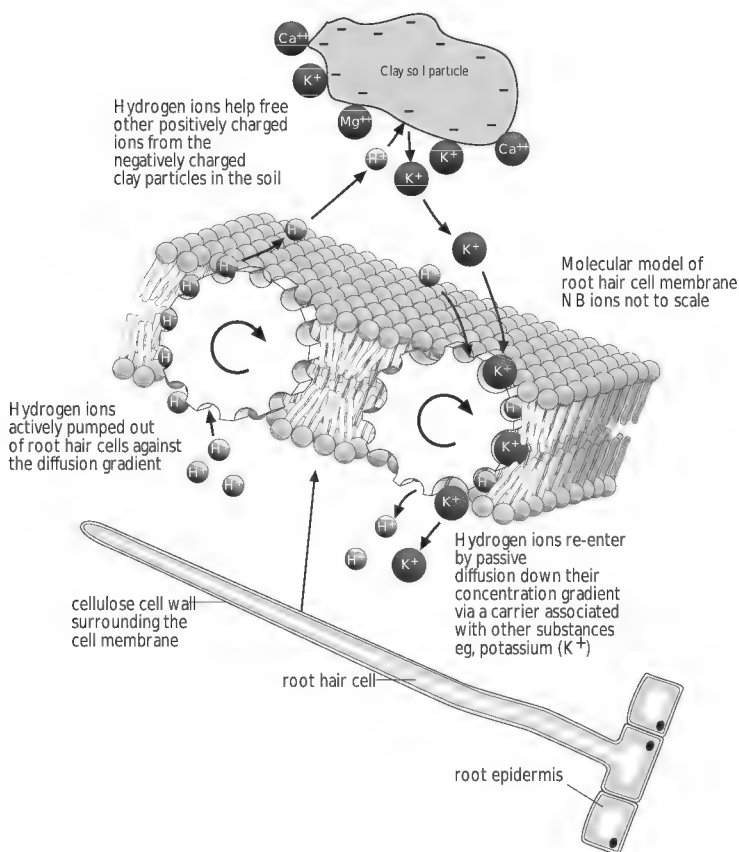


◆ CHECKPOINT SUMMARY

- ◆ The xylem vessels are adapted to the mass transport of water:
- ◆ The lignified walls are waterproof, avoiding absorption and keeping water in the lumen.
- ◆ They are strong to withstand huge negative pressures 'suction' generated by the transpiration stream as the water column is pulled up by cohesion (there is a measurable decrease in diameter of tree trunks under conditions of high transpiration).
- ◆ The smooth lignified walls also offer good adhesion for the water, thus supporting the water column as it moves up the plant.
- ◆ Pits in the walls allow for a continuous system of water to by-pass any air bubbles and breaks in the columns of water; as a result of columns of water breaking under tension or wind movements, or freezing forcing air out of solution in the xylem.
- ◆ Root hairs actively take up inorganic ions and water follows passively down a water potential gradient generating a root pressure.
- ◆ Root pressure can only account for a rise of a few metres but could be important before leaves are fully open in the spring in temperate climates.
- ◆ Once in xylem capillarity aids rise but main force is generated by transpiration at the leaves.
- ◆ Transpiration from the leaves generates the major force for the upward movement of water in the transpiration stream.
- ◆ Water evaporates from the surfaces of the mesophyll tissue in the leaves, and the water vapour diffuses out of open stomata.
- ◆ Stomata have to strike a balance between opening for carbon dioxide uptake and closing to control loss of water vapour.
- ◆ Any factor that increases the water potential gradient between the leaf and the atmosphere will increase the rate of transpiration, e.g. dry air; moving air; and increase in temperature.
- ◆ The evaporation of water in the leaves generates an upward pull on the water in the xylem vessels and tracheids, creating the transpiration stream.

Movement of nutrients

Root hair cells take up inorganic ions from the soil across their membrane by **diffusion** and **active transport**. Root hair respiration produces ATP which is used to supply energy for the active uptake of inorganic ions from the soil solution. Respiration also releases hydrogen ions (protons), which are actively pumped out of the root hair cells, setting up a transmembrane potential and creating both the directional stimulus and energy for the inward flow of nutrient ions. The exported hydrogen ions also release other positively charged ions from the negatively charged clay particles of the soil and make them more available for active uptake by the roots. By this means ions may be taken up by the plant against their concentration gradient.



As the root hair cells accumulate inorganic ions so a diffusion gradient is created and the absorbed ions tend to move inwards via the cytoplasmic connections (plasmodesmata) between the cells of the epidermis and cortex towards the central vascular region. The endodermal cells assist the passage of ions inwards to the xylem by a further active transport mechanism amplifying the concentration difference between the soil solution and the xylem elements in the centre of the root.

If roots are starved of oxygen, as may happen if the soil is flooded, then mineral uptake will stop, as the production of ATP in respiration for active uptake requires oxygen. This has a consequence for water transport because it is the active uptake of mineral ions which provides the gradient along which some water passively enters the root.

At night, the transpiration stream slows down or stops altogether but root hair cells continue the active uptake of ions. The xylem contents therefore become relatively more concentrated at night and, as their water potential is lowered, so water moves by osmosis out of the surrounding cells of the root cortex. This creates a positive pressure of fluid within the root xylem called **root pressure**, the effects of which can be observed by cutting the stem of a plant just above ground and measuring the force with which fluid flows out of the cut from the roots. Root pressure is not a mechanism of water transport; rather a by-product of the active uptake of ions by roots. It is very much less evident during the day when the plant is transpiring because the accumulating ions in the root xylem are quickly carried out of the plant by the transpiration stream.

Studies with radioactive tracers indicate that inorganic ions do not arrive at the leaves in the same relative proportions that they leave the root and could indicate that there is some control over their movement in the xylem. It should be noted that new xylem which is involved in the transpiration stream (sap wood) is produced by the living cambium tissue, which forms a cylinder of living tissue next to the functional xylem. It is suggested that the cambium tissue is removing and adding inorganic ions to the transpiration stream as it passes by. In addition some inorganic ions which accumulate in actively growing regions, can be mobilised to travel to newer actively growing regions in the phloem.

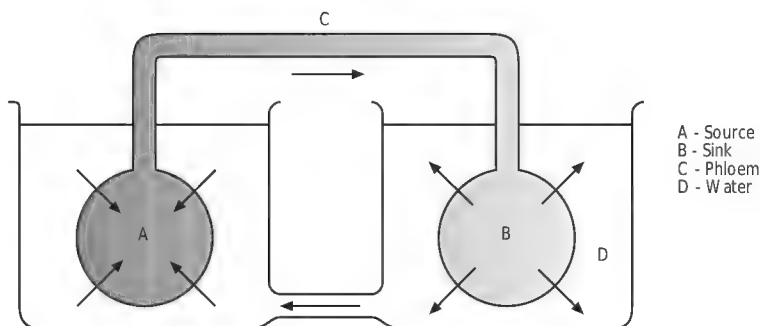
Translocation

Translocation is the name given to the energy-requiring process in which organic materials synthesised by the plants, particularly sucrose are transported in the phloem sieve tube elements. Organic substances synthesised by plants are also known as **assimilates**, as they have been synthesised (assimilated) from simple inorganic substances.

The transport of sucrose and other organic compounds occurs from the point of origin or '**source**' of the organic material to the point of destination or '**sink**'. Typically the main 'source' of sucrose is the photosynthesising leaves. **Transfer cells** found next to sieve tubes, especially in small leaf veins, have a characteristic dense cytoplasm and many organelles, and appear to be involved in transferring substances to and from the sieve tubes of the phloem. The main 'sink' is the respiring roots. However, other 'sinks' are fruits and seeds, and food storage organs e.g. tubers and bulbs, in the autumn. Tubers and bulbs can in turn act as 'sources' and the growing shoots and leaves as 'sinks' in the spring. Thus, transport of sucrose and other organic compounds in the phloem can be in two directions, unlike the xylem where transport of water is only in one direction from the roots towards the leaves. If the 'source' is in the roots and the 'sink' is in the aerial parts, then some organic material can move in the transpiration stream up the xylem.

Mechanism of transport in phloem

Diffusion is not sufficient to account for the observed rates of flow in the phloem. The pressure flow (**mass flow**) mechanism suggests that the 'source' regions have a lower water potential than the 'sinks', due to the presence of greater concentrations of solutes, such as sucrose. This causes water uptake and an increased turgor within the cells at the source. As a result of this and the fact that the two regions are in direct cytoplasmic contact, it is suggested that the organic materials are forced along the resultant hydrostatic (water) pressure gradient, for example from leaves to roots. The flow being maintained by active pumping of sugars into the sieve tube elements in the leaves by companion-transfer cells, and their removal at the 'sink' as a result of their use (e.g. in respiration or conversion to insoluble starch).



Evidence for this mechanism

Aphids (greenfly) feed specifically on living phloem by means of their long tubular mouthparts which they can insert directly into the phloem sieve tube elements. If they are knocked off whilst feeding, their mouthparts are left protruding from the phloem, and the sugary contents, referred to as 'honey dew', may exude out of the broken ends for several days, in volumes up to 100 000 times the volume of the one penetrated sieve tube element. This demonstrates that the contents of the sieve tube elements are indeed under positive pressure as the mechanism would require (in contrast to the negative pressure of the contents in the xylem elements) and that the flow is significant. On a larger and less precise scale, cut phloem in large woody plants can exude sucrose rich sap in volumes up to many litres (dm^3) per day.

Direct measurements of the pressure within the sieve tube elements indicate that the pressure gradients between sources and sinks are in the right direction and great enough to account for the mass flow of sugars over the longest distances required in the tallest trees.

Evidence against this mechanism

Evidence against this mechanism is provided by the fact that the movement is not simply from source to sink. Mature leaves kept in the dark, unable to photosynthesise and supply their own sugars for respiration, do not import sugars and eventually die. This observation supports the suggestion that the growth substance auxin is in some way involved. Mature leaves have low auxin levels, whereas virtually all 'sinks' are actively growing tissues e.g. roots, food storage organs and apical meristems (dividing cells of shoot tips) and have high auxin levels. Furthermore, when auxins are applied artificially to a region of a plant the flow of sucrose in the phloem is redirected towards it.

Observations that translocation relies on the activities of living cells, argue against the simple mass flow mechanism, which could operate more easily through dead empty elements like the xylem, as long as the loading and unloading regions were living. These observations include the following:

- ▼ translocation only occurs in young phloem sieve tube elements with actively streaming cytoplasm;
- ▼ metabolic poisons (e.g. those inhibiting respiration) inhibit translocation;
- ▼ when the phloem tissue is killed with heat or poisonous substances translocation stops;
- ▼ companion cells are metabolically active along the length of the sieve tube elements, suggesting some role in translocation.

The use of radioactive tracers and ringing experiments to determine the movement of ions and organic substances through plants

Certain substances (elements) have radioactive forms (radioactive isotopes). Radioactive isotopes have the same chemical properties as the non-radioactive form of the element, but are unstable and emit radiations known as 'radioactivity'. These emissions can be detected by a Geiger counter, and by photographic film to produce an autoradiograph, so that the presence of the radioactive isotope of an element can be located. As radioactive isotopes have the same chemical properties as the normal form, they can be used as **radioactive tracers** to trace the path of an element such as carbon (and compounds containing that element such as sucrose) through the plant.

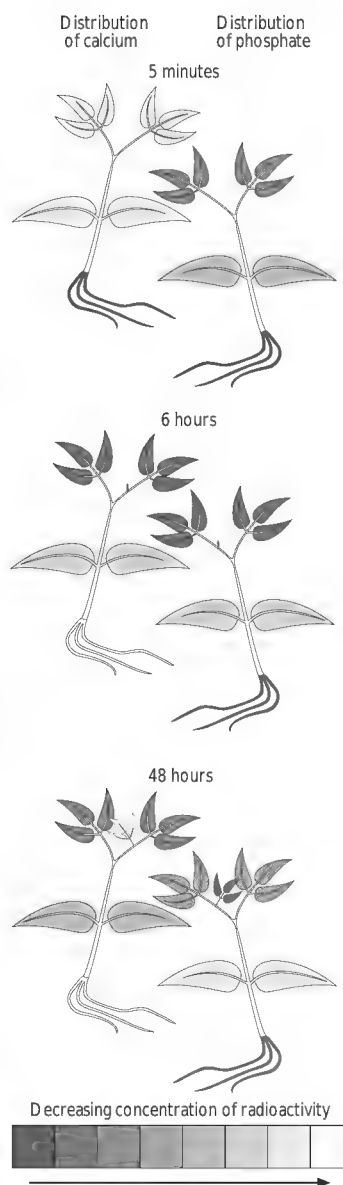
The roots and leaves of plants can be exposed to radioactive isotopes and their subsequent movement through the plant can be traced to determine the movement of ions and organic substances through plants in the xylem and phloem. As the phloem is situated outside of the xylem in woody stems, it can be removed easily by '**ringing**' leaving the central xylem intact, allowing insights into the roles of the xylem and phloem.

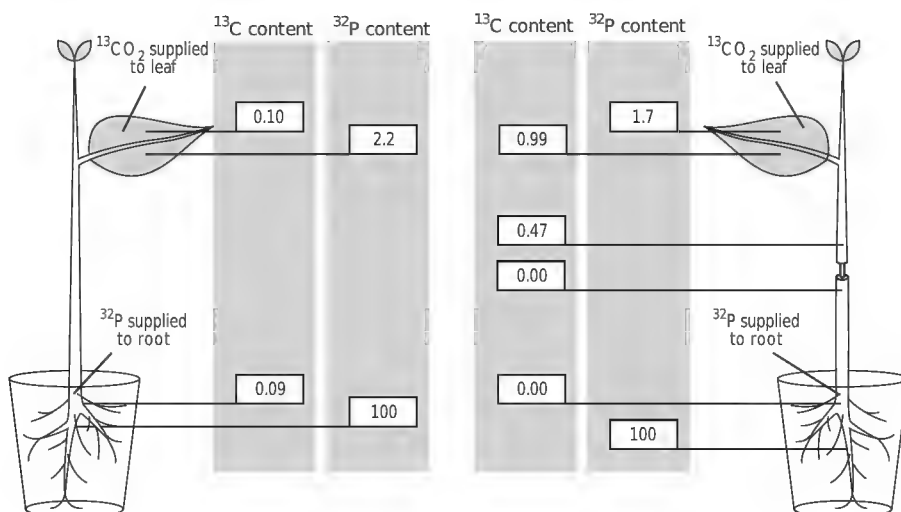
If the roots are exposed to radioactive calcium and phosphorus ions in calcium phosphate solution for an hour, and then removed to a non-radioactive solution, and pressed onto photographic film after 5 minutes, 6 hours, and 48 hours, the uptake of the ions and subsequent movement in the plant can be studied. It can be seen that the phosphate ions quickly reach the young leaves, and transfer to each batch of new young leaves as they emerge, whereas the calcium arrives more slowly in the young leaves and remains there. Ringing the stem has no effect on these movements, indicating that the movement up the plant is in the xylem. However, for the phosphate ions to move from one set of leaves to another, they must also be moved in the phloem. The different rates of arrival in the leaves indicate that the uptake and movement of the two ions in the xylem differs, not what would be expected from them being taken up by solvent drag and being swept along passively in the transpiration stream.

When leaves are exposed to radioactive carbon in carbon dioxide, the radioactivity eventually reaches the roots, but ringing the stem (removing the phloem) stops this downward movement, indicating that it is in the phloem.

Sections of the stem can be taken and autoradiographs produced, but lateral transfer occurs between xylem and phloem so the results can be inconclusive, for example when radioactive ions are taken up by the roots they appear in both the xylem and the phloem. Waxed paper barriers placed between the xylem and the phloem prevent this and the radioactive ions appear mainly in the xylem.

Radioactive tracer studies also indicate that substances move in different directions at the same time in the phloem, which would argue against the mass flow mechanism, although this could be occurring in different sieve tube elements, which would still be explicable in terms of the mass flow theory.





◆ CHECKPOINT SUMMARY

- ◆ Mineral ions are taken up by the root hairs, which have a large total surface area, by diffusion and active transport. Only actively growing roots absorb substances from the soil.
- ◆ Mineral ions are transported by solvent drag in the transpiration stream from the roots to the leaves.
- ◆ However, they arrive in different proportions and at different rates, indicating that the process is not simply one of being swept up by solvent drag.
- ◆ The cylinder of active living cambium lies next to the water transporting xylem of the sap wood, and may have a role in importing and exporting ions to and from the transpiration stream.
- ◆ Translocation of assimilates (organic substances synthesised in the plant by photosynthesis) e.g. sugars, amino acids, hormones, nucleic acids etc. occurs in the phloem tissue.
- ◆ Organic materials move from an area of manufacture (source) to an area where they are used (sink). Sucrose thus moves from the leaves (sources) to actively growing and respiring regions such as the roots, flowers, and new buds (sinks).
- ◆ Phloem tissue (unlike most of the Xylem) is composed of living cells and elements.
- ◆ Mechanism of movement still not fully understood.
- ◆ Mass flow mechanism postulates high hydrostatic pressure in sources and low in sinks, which results in the mass flow of sucrose in solution from sources to sinks. Transfer cells in the leaves being responsible for moving sugars into the sieve tube elements.
- ◆ Contents are under positive pressure but there is no clear evidence of the necessary pressure gradients.
- ◆ Movement occurs in both directions, although this could be accounted for by considering the mass flow mechanism in respect to single columns of sieve tube elements within the phloem tissue as a whole.
- ◆ Movement of assimilates is stopped if the phloem is poisoned with a respiratory inhibitor; exposed to high or low temperatures i.e. translocation is an active process, only occurring in those sieve tube elements showing cytoplasmic streaming.
- ◆ Ringing removes all tissues (including the phloem) outside of the xylem, and radioactive tracers e.g. ^{32}P and ^{14}C allow the movement of materials in the xylem and phloem to be detected.
- ◆ ^{32}P supplied to the roots will pass through the ringed region, whereas ^{14}C taken up the leaves and assimilated into sucrose will accumulate above the ring.

Transport in mammals

The living cells of the body obtain oxygen and nutrients from the fluid environment which surrounds them and they excrete waste substances into this environment. They are surrounded by a fluid medium called **tissue fluid** or extracellular fluid, with which they exchange materials. This is referred to as the '**internal environment**' and for exchange to occur between the internal and the external environment in larger organisms, specialised systems have evolved. Also essential to this process is an efficient circulatory system composed of closed blood vessels. In the mammalian circulatory system, the blood flows entirely within a virtually closed system of vessels from the heart in the arteries, arterioles, capillaries, venules and veins back to the heart (although there are invariably some small blood spaces where the blood leaves the vessels e.g. in the liver).

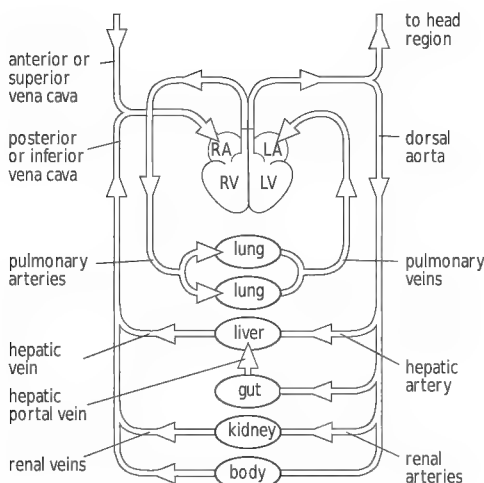
The blood transports respiratory gases, metabolites (nutrients and materials synthesised within the body), metabolic wastes (e.g. urea). It also acts as a chemical messenger service, carrying hormones from the glands where they are produced to the target organs upon which they act.

The double mammalian circulation

Closed circulations can be either single or double. In single circulation systems the blood only passes through the heart once during each complete circulation of the body. Therefore the blood passes through two sets of capillaries (e.g. in fish, the gills and the body tissues) before returning to the heart. This results in a high resistance to flow, a slow flow, and ultimately a low pressure in the tissues.

The mammalian heart has four chambers, and is divided into right and left 'halves'. Blood passes through the heart twice during each complete circulation of the body. This is referred to as a double circulatory systems. Double circulatory systems are more efficient than single systems. The blood travels from the heart to the lungs and back to the heart in the **pulmonary circulation**, and then from the heart around the rest of the body and back to the heart in the **systemic circulation**.

This arrangement means that the blood can be pumped through the capillaries of the delicate alveoli of the lungs at a lower pressure, than that of the systemic circulation in which a higher pressure is required for the circulation around the body. The lower pressure is a result of the less muscular wall of the right ventricle, and the lower resistance presented by the relative thinness of the elastic walls of the pulmonary arteries, and their arterioles. If the blood pressure was any higher in the pulmonary circulation (as it sometimes is in people suffering from hypertension or 'high' blood pressure) the lungs would be at risk of filling with tissue fluid, which would have serious consequences for gas exchange. Passage through the pulmonary capillaries further lowers the blood pressure and the return of the blood to the left side of the heart allows the left ventricle to pump the blood powerfully round the body under a raised pressure.



◆ CHECKPOINT SUMMARY

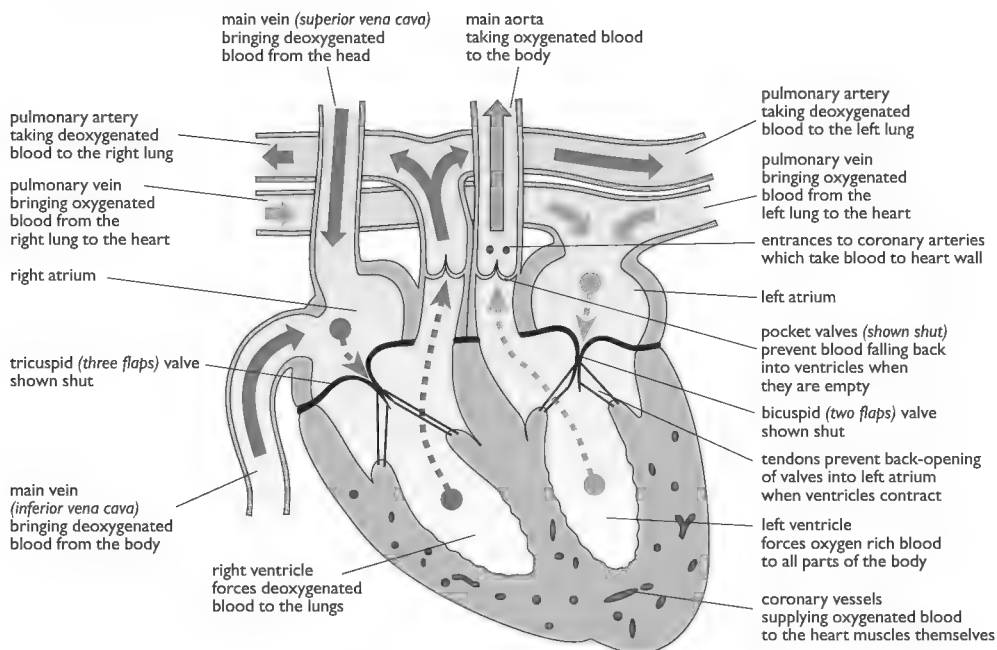
- ◆ The functions of the circulatory system include the transport of oxygen and carbon dioxide between the lungs and the tissues of the body, metabolites to and from the gut, liver and kidneys, metabolic wastes from the liver to the kidneys, and hormones from and between the endocrine glands.
- ◆ In single circulations blood only passes through the heart once on each complete circulation of the body.
- ◆ Means that blood passes through two sets of capillaries on each circulation, respiratory surface and body tissues.
- ◆ Represents large resistance to overcome before blood returns to heart, resulting in slow flow and low pressure in veins which are typically large blood sinuses to lower resistance to flow.
- ◆ Closed systems blood almost entirely restricted to vessels: arteries, arterioles, capillaries, venules, veins.
- ◆ Tissue fluid exuded to bathe tissues directly.
- ◆ Double circulation blood passes through heart twice on each circulation.
- ◆ Pressure relatively low to lungs.
- ◆ Pressure raised for systemic circulation to body giving high pressure and fast flow.

The structure of the mammalian heart and coronary circulation

The heart is situated slightly to the left of the midline of the chest, protected by the ribs and by a tough membrane (pericardial membrane) which surrounds it in a fluid filled pericardial cavity.

It is composed of four muscular chambers, two upper thinner walled atria, and two lower thicker walled ventricles. The right and left sides are divided from each other by a muscular septum. The right atrium receives blood in the venae cavae from the body, and the left atrium receives blood in the pulmonary veins from the lungs. (Note that diagrams of internal organs are always viewed from the front of the body, so that the right atrium and right ventricle appear on the left side of the diagram.)

The atria are separated from the main pumping chambers, the right and left ventricles, by flaps of fibrous tissue which act as one way valves. These atrio-ventricular valves differ from each other. The **tricuspid** valve on the right has three flaps, and the **bicuspid** valve on the left has two. These are attached to tendons and muscles which prevent them opening upwards under pressure.



Inside the entrance of the main arteries which leave the heart, the aorta and pulmonary artery, are two more sets of valves called semi-lunar or pocket valves which when filled with blood block the entrance to the **coronary artery** which supplies the heart muscle with nutrients and oxygen. The artery spreads its branches all over the surface of the heart. Deoxygenated blood is collected into the coronary vein which empties directly into the right atrium. The heart requires its own blood supply despite being filled with blood, as the blood that it is pumping is passing through too quickly, and the heart walls are too thick for diffusion to supply the needs of the heart muscle fibres.

The walls of the atria are less muscular than those of the ventricles, and the wall of the left ventricle is more muscular than that of the right ventricle. These differences reflect the different pressures that need to be generated in the chambers. The atria only have to pump blood into the ventricles. The right ventricle pumps blood to the lungs at a relatively low pressure. The lungs are close to the heart, and too high a pressure could damage the delicate alveoli and result in the filling of the lungs with fluid. The left ventricle must generate a high pressure to pump blood right around the body.

However, it is important to remember that the volumes of the lumens (cavities) of the chambers on the right side of the heart are the same as those on the left side of the heart, otherwise the right side would not be able to supply the left side with sufficient blood.

◆ CHECKPOINT SUMMARY

- ◆ External appearance of heart shows small 'flap-like' atria, coronary blood vessels, fat deposits, and major vessels entering and leaving (venae cavae, pulmonary arch, and aortic arch).
- ◆ Coronary arteries arise just above the pocket valves at base of pulmonary and aortic arches, and supply cardiac muscle of heart wall with its own blood supply. Coronary veins return blood to right atrium.
- ◆ Internal structure of two atria and two ventricles separated by bicuspid and tricuspid valves.
- ◆ Chordae tendinae and muscles prevent back-opening of bicuspid and tricuspid valves when ventricles contract.
- ◆ Atria walls thinner than ventricle walls.
- ◆ Pocket valves at base of pulmonary artery and main aorta prevent backflow of blood into ventricles when they relax.
- ◆ Left ventricle wall thicker than right ventricle wall to pump blood around body.
- ◆ Right ventricle wall thinner than left ventricle wall as only has to pump blood via pulmonary circulation around lungs, reduced pressure also prevents formation of tissue fluid in alveoli.
- ◆ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.

The cardiac cycle

The sequence of events that occurs during the filling and emptying of the heart is known as the cardiac cycle. At a rate of 70 beats per minute (bpm) the complete cycle takes about 0.86 seconds. It is a continuous sequence of events that occurs simultaneously on the left and right sides, but for the purposes of explanation it is convenient to consider it as occurring in a series of stages.

There is a point in the cardiac cycle when all the heart valves are shut, which can be taken as the starting point of the cardiac cycle.

Blood returning under low pressure in the main veins (superior and inferior venae cavae) from the upper and lower body enters the right atrium, and at the same time blood returning from the lungs in the pulmonary veins enters the left atrium.

The atria fill with blood, and the rising pressure of the blood in the atria pushes open the tricuspid and bicuspid valves, and both ventricles begin to fill.

As the heart fills with blood both atria contract (**atrial systole**) forcing even more blood into the ventricles. These are now stretched, and they both contract (**ventricular systole**) forcing the blood upwards.

This upsurge of blood forces the tricuspid and bicuspid valves shut. These valves are prevented from back-opening into the atria by tough tendons, which are held taut by contraction of the papillary muscles to which they are attached. The closing of these valves makes the first heart sound (described as 'lub').

The blood is thus forced along the pulmonary artery to the lungs, and along the main aorta to the rest of the body, pushing open both sets of pocket or semi-lunar valves on the way.

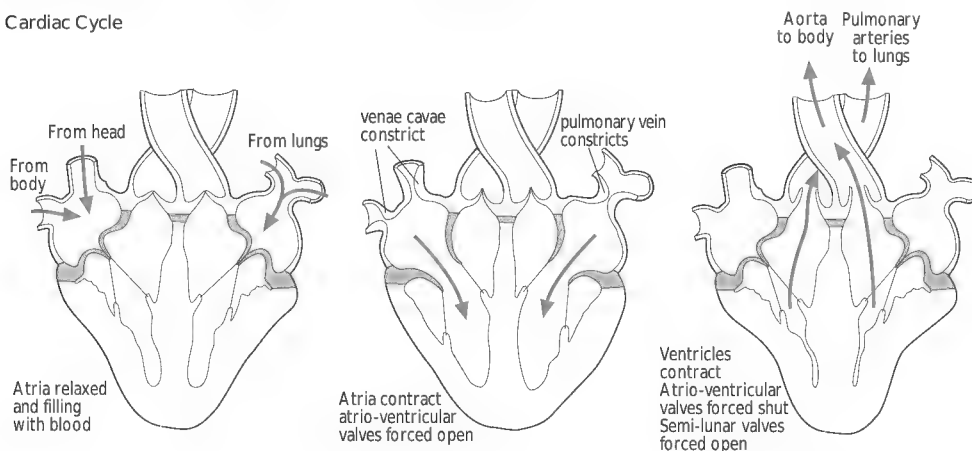
When the ventricles relax (**ventricular diastole**) the blood tends to fall back down the pulmonary artery and main aorta under gravity, thus filling and shutting the pocket valves. The closing of these valves makes the second heart sound (described as 'dup'). All valves are now shut and the cycle is repeated.

The heart sounds can be heard with the use of a stethoscope.

CHECKPOINT SUMMARY

- ◆ The cardiac cycle refers to the events of a complete filling and emptying of the heart.
- ◆ It is a continuous cycle, the start point of which can be taken when heart is empty and all valves shut.
- ◆ Atria fill and internal pressure rises forcing bicuspid and tricuspid valves open.
- ◆ Ventricles fill so that whole heart full.
- ◆ Atria contract (atrial systole) so that ventricles overfilled and stretched.
- ◆ Ventricles contract with a force proportional to their degree of stretch (ventricular systole).
- ◆ Blood forced up shutting bicuspid and tricuspid valves (first heart sound) and opening pocket valves as blood forced up pulmonary artery and aorta.
- ◆ Ventricles relax (ventricular diastole) blood falls back in pulmonary artery and aorta shutting pocket valves (second heart sound).

Cardiac Cycle



Myogenic stimulation and the coordination of the cardiac cycle

Cardiac muscle is myogenic, that is the stimulus for contraction arises internally, rather than externally from branches of the nervous system, as seen with skeletal muscle.

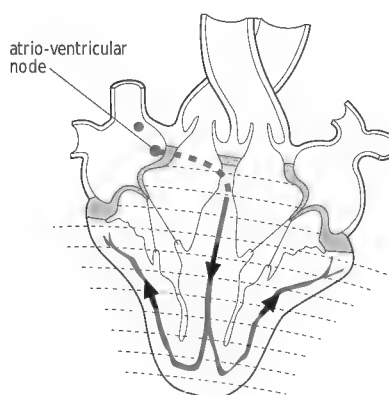
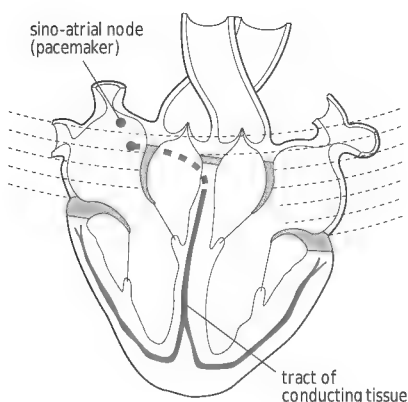
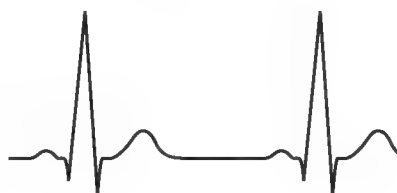
The **sino-atrial node** (SA node) or 'pacemaker' is a mass of specialised tissue in the right atrium from which coordinating waves of electrical activity originate and radiate through the muscle of the heart wall. The sino-atrial node thus coordinates the basic rhythm of the heart contractions.

The wave of excitation spreads rapidly through the interconnected cardiac muscle fibres of the atria allowing both to contract simultaneously. A band of fibrous connective tissue between the atria and ventricles prevents the wave of excitation spreading down into the ventricles.

Another mass of specialised tissue, the **atrio-ventricular node** is located at the bottom of the atria. It is stimulated by the waves of electrical impulses radiating from the SA node, and transmits the impulses through the insulating band of connective tissue between the atria and ventricles. The impulse travels to the base of the ventricles in a tract of conducting tissue, composed of modified cardiac muscle fibres and neurones known as Purkyne tissue, from where the impulses radiate upwards through the cardiac muscle of the ventricles.

This pattern of the spread of excitatory waves through the heart, ensures that the atria contract first to force the blood **down** into the ventricles, and that the ventricles subsequently contract to force the blood **up** into the pulmonary arteries and main aorta. The spread of the wave of excitation throughout the heart can be detected by electrodes attached to the skin of the chest and displayed as an electrocardiograph (**ECG** trace).

ECG trace of electrical activity of heart



Although the sino-atrial node initiates contractions of the heart it cannot vary the rate of stimulation on its own. The basic rate of the sino-atrial node, can, however, be altered by a variety of influences, over a range from about 30 beats per minute (bpm) to as many as 220 bpm.

It is influenced by the activity of the sympathetic and parasympathetic nerves of the autonomic nervous system, which originate from a control centre in the brain.

The sympathetic nerve endings secrete noradrenaline, which stimulates an increase in the heart rate directly.

The parasympathetic nerves, release acetylcholine which causes a decrease in the heart rate. During exercise, the progressive increase in the heart rate is due at first to a decrease in parasympathetic activity, and then to the increasing activity of the sympathetic nervous system.

Also, in response to a general activation of the sympathetic nervous system, adrenaline is released from the adrenal glands, which also increases the heart rate, acting via the blood circulation.

Stimuli for these changes include the levels of blood carbon dioxide, pH, and temperature. Increases in these levels, associated with increased activity, result in an increase in the rate of contraction of the heart (beats per minute).

The structure and roles of arteries, veins and capillaries

In mammals the blood circulates around the body in a continuous system of blood vessels. From the heart, blood travels in the arteries and arterioles, into the capillaries supplying the tissues, and then returns to the heart in the venules and veins. All blood vessels are lined with smooth endothelium (epithelium found lining tubes) which reduces friction. Arteries and veins have varying amounts of muscle in their walls, which is always involuntary (smooth / unstriated) muscle under the control of the autonomic nervous system and hormones.

Arteries

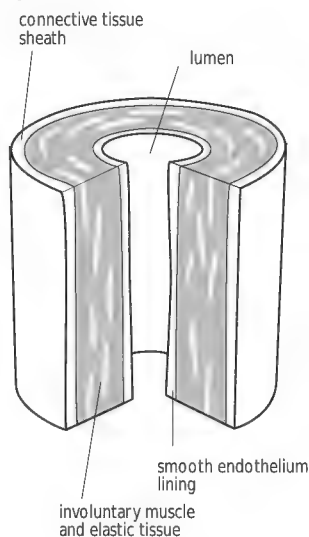
Arteries close to the heart have a large cross sectional area, and thick elastic walls. Arteries are stretched by the cardiac output when the heart contracts, and they recoil when the arterial blood pressure drops as a result of the heart relaxing between beats. The recoil of the elastic artery walls in this way assists the circulation of the blood around the body. It helps smooth the flow between contractions of the heart, and helps to maintain the blood pressure. This stretching and recoiling of the arteries is felt as the pulse in places where arteries come close to the surface of the body (the inside of the wrist, the side of the neck, and in the temple).

The main artery leaving the left ventricle of the heart, the aorta, branches into arteries supplying all the main regions of the body. Further from the heart, there is a gradual transition from the elastic arteries to muscular arteries that have circular layers of involuntary muscle in their walls. These arteries branch into smaller **arterioles** the walls of which, although thinner, also have circular layers of involuntary muscle. The state of contraction or 'tone' of these muscle

◆ CHECKPOINT SUMMARY

- ◆ Cardiac muscle is myogenic.
- ◆ Rate modified by sino-atrial node (pacemaker) in wall of right atrium.
- ◆ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ◆ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ◆ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from where it radiates up through the walls back to the connective tissue barrier.
- ◆ Detected by electrodes on the skin as an ECG.
- ◆ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline.
- ◆ Pressure receptors in the main veins and arteries close to the heart detect pressure changes and regulate the cardiac output by reflexes via the medulla of the brain.
- ◆ All influences on heart rate coordinate heart rate and therefore blood supply to body (cardiac output) with demands of body.

Artery in section



layers alters the diameter of these vessels, which changes the resistance to the flow of the blood, which in turn effects the blood pressure and distribution of the blood to different parts of the body. The arterioles penetrate all tissues of the body and connect to beds of finely branching capillaries.

Capillaries

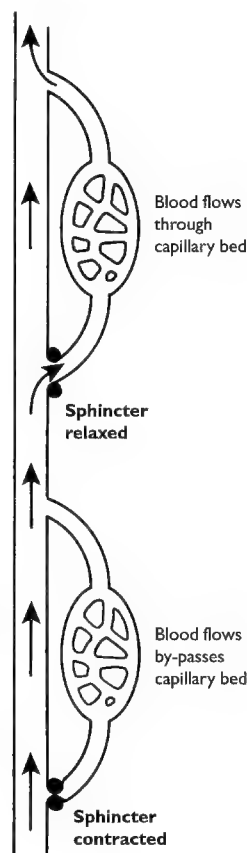
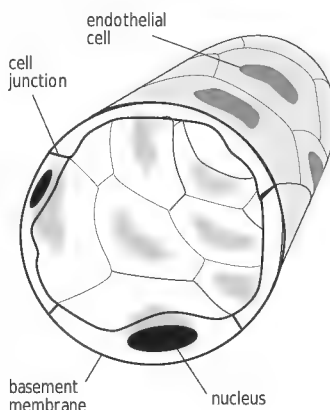
Capillaries form a fine network which penetrate all tissues. They have the smallest diameter of all blood vessels, about 6-8 μm (0.007 mm), which is the same as that of the red blood cells. For this reason the red cells are forced to move slowly through the capillaries in single file, ensuring a short diffusion distance between the corpuscles and the tissues. Capillary walls are just one cell thick, which further aids exchanges by diffusion between the blood and the tissues. The huge number of capillaries provide a very large total surface area across which these exchanges occur. As more capillaries open up in working muscles, the surface area between the blood and tissues is increased, and the diffusion distance between the two is decreased, resulting in more rapid and efficient exchanges between them. The blood pressure and rate of flow both drop in the capillaries. The slow flow also increases the time available for exchange of materials between the blood and the tissues.

There are so many capillaries in the body that they cannot all be supplied with blood at the same time. Consequently, there is competition for blood between different regions of the body, especially during exercise, when blood must be shunted to the working muscles, and consequently withdrawn from other regions. For example, when the body is at rest, about 45% of the cardiac output passes through the capillaries of the gut wall and associated glands, and the kidneys. During maximum exercise this can be reduced to about 3% of the cardiac output, as blood is redirected to the working muscles. The reduced flow rate is compensated for by a greater extraction of oxygen from the blood, by these tissues. The shunting of blood between competing tissues is achieved by constriction and dilation of the arterioles, and of the arterio-venous vessels, which are direct connections between the arterioles and venules. The entrances to the capillary beds are controlled by circular precapillary sphincter muscles which, when contracted, shut off the capillaries and when relaxed, open them.

Estimated blood flow in cm^3 per minute, to different organs/systems in a trained male at rest and during maximum effort.

Organ system	At rest	%	Max. effort	%
Skeletal muscle	1000	20	26 000	88.00
Coronary vessels	250	5	1200	4.00
Skin	500	10	750	2.50
Kidneys	1000	20	300	1.00
Liver & gut	1250	25	375	1.25
Brain	750	15	750	2.50
Whole body	5000	100	30 000	100.00

Section of typical capillary



Veins

Capillaries join up to form **venules**, which in turn join to form veins which return the blood to the heart. The individual veins have a larger cross sectional area than the comparable arteries, and as there are more veins than arteries, the veins therefore also have a greater total cross sectional area. The walls of the veins are thinner and less elastic than those of the arteries, and in the veins of the legs and arms there are semi-lunar or pocket valves at intervals along their length. These valves oppose any back flow of blood under gravity, and ensure one-way flow of blood to the heart when the veins are 'massaged' by movement of surrounding tissues (especially contracting skeletal muscles). The thin walled veins with their large cross section present little resistance to the flow of the blood, so that although the blood pressure in the veins is low after passage of the blood through the capillary beds, the remaining pressure still helps move the blood in the veins back to the heart.

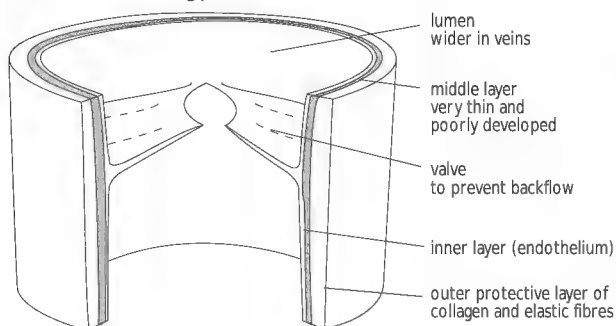
Because the blood in the veins is under low pressure, and their walls are thin, the veins are easily compressed by the smallest movements of the surrounding structures, particularly the skeletal muscles. As the muscles contract and relax during exercise they exert a massaging effect on the deep veins, especially for example in the legs, when running, swimming, or cycling. This massage effect of the 'muscle pump' is random and in no particular direction, but the pocket valves in these veins ensure that the flow is one-way, back to the heart.

In addition, breathing movements assist the return of blood in the veins to the heart. On breathing in, the diaphragm contracts and moves downwards. This decreases the pressure within the thorax, and increases the pressure within the abdomen. These changes in pressure compress the large veins in the abdomen, and assist the flow of blood into the veins of the thorax which return blood to the heart.

At rest the veins act as a large reservoir of blood for use when circulatory demands increase, for example during exercise. During exercise when the output of blood from the heart (cardiac output) increases, the muscle fibres in the walls of the veins are stimulated to contract (venous tone) and the veins constrict. As a result a larger proportion of the venous blood is shunted back to the heart, especially from the veins in the legs and the abdomen. This is especially important in preventing blood from 'pooling' in the legs under the force of gravity during upright exercise, and immediately afterwards.

In these ways the venous return of blood balances the rising cardiac output during exercise. This is essential as the heart would be unable to maintain a high cardiac output unless it was receiving an equal volume of blood back from the veins.

Section of vein showing pocket valve



◆ CHECKPOINT SUMMARY

- ◆ Elasticity of arteries is important in smoothing flow of cardiac output.
- ◆ Finer branches and arterioles are main sites of generation of resistance to blood flow.
- ◆ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ◆ Capillaries have large total cross sectional surface areas. Therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ◆ Diameter of capillary same as red blood corpuscles thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ◆ Plasma minus proteins exuded through thin walls to bathe tissues directly.
- ◆ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ◆ Pocket valves ensure one way flow back to heart.
- ◆ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

BLOOD AND BODY FLUIDS

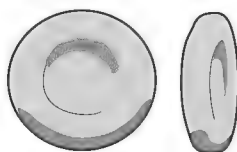
Composition of the Blood

Blood consists of the fluid plasma, which carries red blood cells, white cells, and fragments of cells from the red bone marrow known as platelets.

Plasma consists of 90% water, and 10% materials in suspension and solution. Plasma proteins, formed mainly in the liver, include albumin (to which the plasma calcium is bound), globulins (some of which are antibodies and others are important in the carriage of hormones and vitamins), and fibrinogen (which is important in blood clotting). These proteins also have an important function in buffering the blood (preventing sudden changes in acidity and alkalinity). Plasma proteins are also involved in regulating the movement of water between blood and tissues, they lower the water potential of the plasma which helps to control the volume of tissue fluid being formed and reabsorbed. Plasma also contains many dissolved organic and inorganic substances which are being transported, e.g. amino acids, hormones, glucose, fats, urea, creatine, bicarbonate, some oxygen and carbon dioxide. The characteristic yellow straw colour comes from a pigment called bilirubin which is formed from haemoglobin when old red blood cells are broken down in the liver.

Red blood cells (erythrocytes) lose their nucleus and most of their cytoplasmic organelles in their process of maturation in the red bone marrow. They become 'corpuscles' with a flexible membrane, filled with the oxygen carrying pigment haemoglobin. The loss of the nucleus accounts for their biconcave shape which increases their surface area to volume ratio. The total surface area of the red blood cells in man is about 3500 m² and this facilitates the exchange of gases between the red cells and the tissues. The biconcave shape also gives them some resilience in absorbing water without bursting should the plasma become temporarily diluted for any reason. The flexible membrane enables them to 'squeeze' through capillaries.

Red blood cells comprise about 30-40% of the blood volume. This can be determined by centrifuging a blood sample which results in the red blood cells being forced down to the bottom of the sample to give a 'packed red cell volume' or haematocrit. The haematocrit (and the red blood cell count) are proportional to the haemoglobin content of the blood which is quoted in grams per litre (decimetre cubed (dm³), with normal values being within 140-180 for men, and 115-160 for women. (Clinically the figures are quoted in grams per decilitre (one tenth of a litre) and are given as 13 - 17g for adult males and 11.5 - 16.0g for adult females.) Levels below the lower limits being known as anaemia.



Red cell approx. 7µm in diameter

White cells (leucocytes) form the basis of the immune system. They comprise just 1% of the total blood volume. There are four main types of leucocyte which differ in both structure and function. They are all found in the blood, although most actually function outside of the capillaries in the tissues.

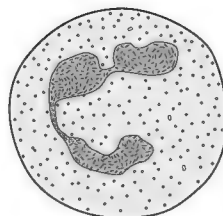
Neutrophils are the most common type and make up approximately 70% of leucocytes. They are small phagocytic cells which engulf foreign particles e.g. disease causing invading micro-organisms (pathogens). They have a characteristic multi-lobed nucleus, surrounded by granular (grainy) cytoplasm.

Eosinophils possess a bi-lobed nucleus and granular cytoplasm, these leucocytes usually only comprise 1.5% of the total leucocyte population. However, in the blood of individuals suffering from allergic conditions, the proportion of eosinophils is increased as they play a role in allergic responses. They are also involved in the destruction of large parasites such as flatworms.

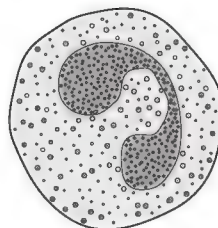
Monocytes can be identified by their large 'bean-shaped' nucleus and non-granular cytoplasm. They originate in the bone marrow, spend a short time in the blood, and then settle in tissues where they become known as **macrophages**. Monocytes secrete chemical known as cytokines which are essential for the functioning of the immune system. Macrophages are involved in the phagocytosis of micro-organisms and other large particles. Macrophages are also found in the alveoli of the lungs where they attack pathogens entering via the air.

Lymphocytes are involved in specific immune responses to pathogens or other foreign cells. They are round in shape with a large, densely staining nucleus. The small amount of cytoplasm is non-granular. There are two main types:

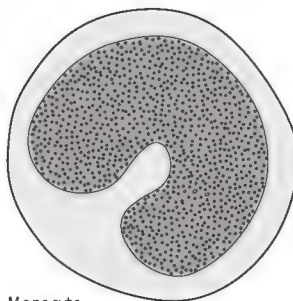
B-lymphocytes which produce antibodies and **T-lymphocytes** which are involved in the direct killing of infected cells.



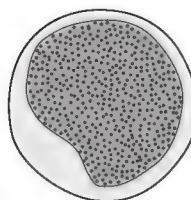
Neutrophil



Eosinophil



Monocyte



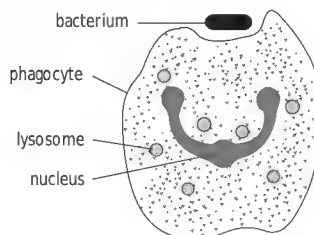
Lymphocyte

Role of leucocytes in phagocytosis

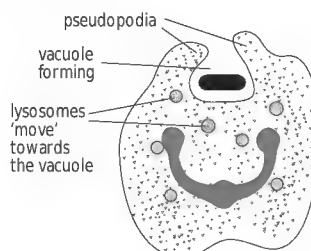
Phagocytosis is the process by which pathogens, other foreign material and dead or infected cells are engulfed and digested by neutrophils or monocytes/macrophages (collectively known as **phagocytes**). These phagocytes are non-specific in their actions so will deal with any type of foreign material which they come across. Phagocytes are found in the blood and the lymphatic system, especially in the lymph nodes as well as in the intercellular spaces of tissues.

- ▼ Neutrophils appear in blood, lymph and tissue sites, and macrophages are found primarily in tissues. This is important as it allows them to act in any tissue which becomes infected with pathogens.
- ▼ The process of phagocytosis in both neutrophils and macrophages involves several stages.
- ▼ The phagocytes comes into direct contact with the foreign particle or microorganism.
- ▼ The cell membrane and cytoplasm of the phagocyte moves out forming 'pseudopodia' around the particle or micro-organism.
- ▼ The particle or micro-organism is enclosed in a vacuole (called a phagosome) formed from the cell membrane of the phagocyte.
- ▼ Lysosomes in the cytoplasm, containing enzymes and other chemicals, fuse with the phagosome and discharge their contents.
- ▼ The micro-organism or other cell material is killed and digested, and the products of digestion are absorbed by the phagocyte or released from the cell.

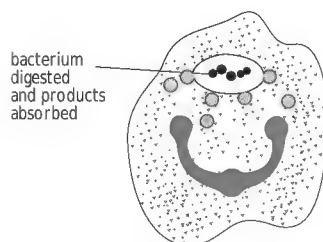
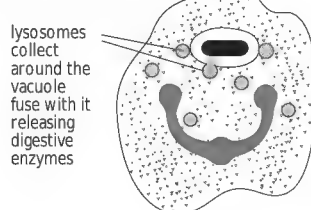
Phagocyte 'moves' towards bacterium



Vacuole forming



Vacuole formed



◆ CHECKPOINT SUMMARY

- ◆ Blood consists of fluid plasma with erythrocytes (red blood cells), and leucocytes (white blood cells) and blood platelets.
- ◆ Plasma composed of 10% materials in suspension and solution.
- ◆ Plasma proteins wide variety of functions and act to buffer changes in pH.
- ◆ Materials carried in solution not strictly part of the plasma.
- ◆ Red blood cells lose nucleus in development and become biconcave corpuscles of haemoglobin.
- ◆ Red blood cell volume 30-40% of total blood volume.
- ◆ Large surface area to volume ratio individually due to biconcave shape, and huge total surface area due to small size (6-8 mm) and huge numbers.
- ◆ Males higher blood count/haemoglobin than females.
- ◆ There are several types of leucocytes (neutrophils, eosinophils, monocytes and lymphocytes) and they form basis of immune system.
- ◆ Leucocytes engulf foreign particles e.g. bacteria and viruses by phagocytosis, and secrete antibodies against foreign antigens, including bacteria and viruses.
- ◆ Platelets are fragments of white cells.

Role of leucocytes in the secretion of antibodies

B-lymphocytes are involved in the specific immune response to pathogens (or other foreign antigens) via the production of antibodies.

On the cell surface membrane of B-lymphocytes are a number of specific antigen receptors or membrane bound antibodies. These are sites to which antigens on the surface of pathogens or other foreign material may become attached, leading to a sequence of events in which free antibodies are produced to destroy the foreign material.

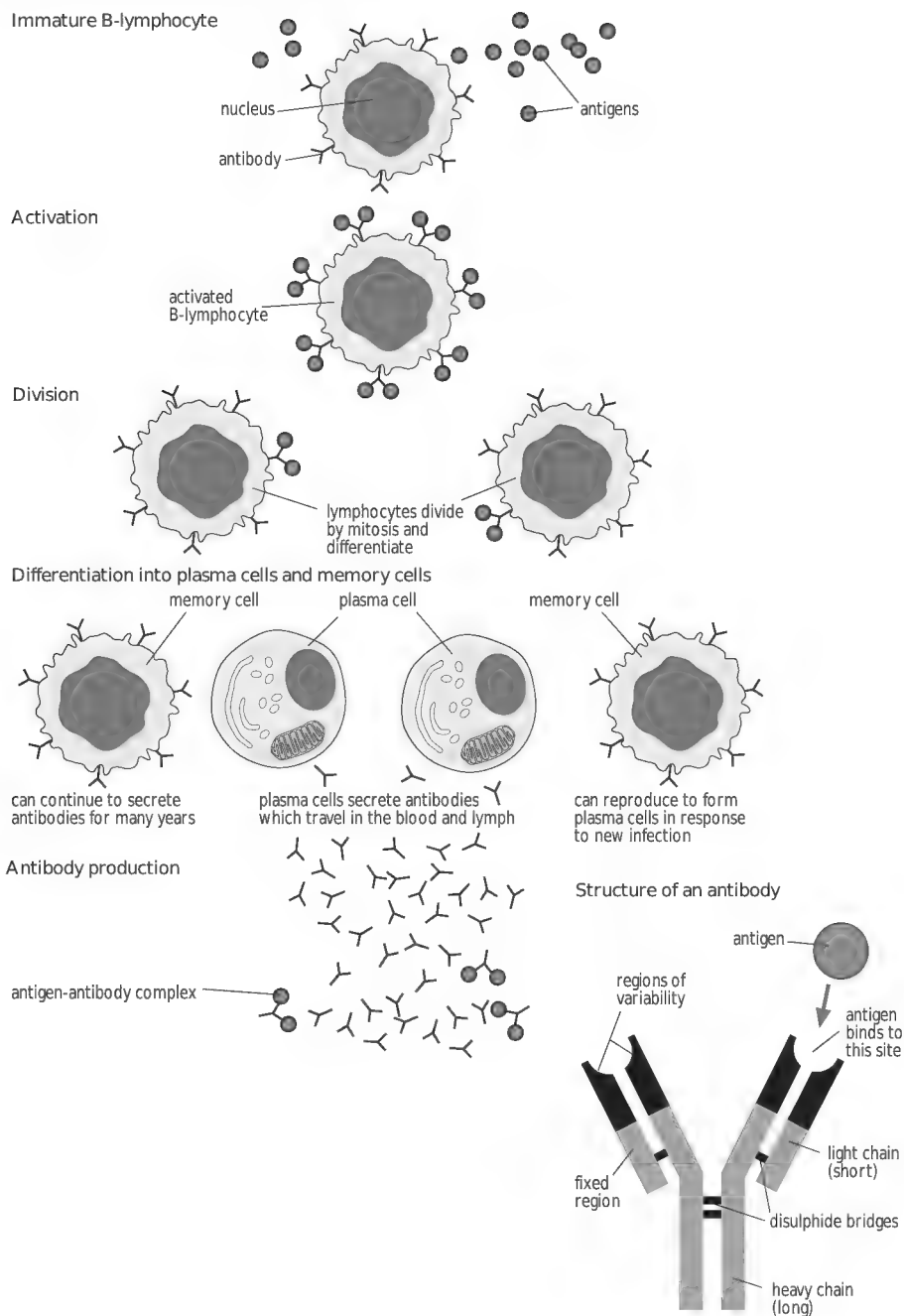
Antibodies are a type of protein molecule known as immunoglobulins which are secreted by activated B-lymphocytes when a specific antigen is encountered. Antibodies do not directly destroy foreign material but target it for destruction by other branches of the immune system, including phagocytes.

Sequence of events in the production of antibodies

- ▼ Antigens on surface of foreign material come into contact with their specific antigen receptor on a B-lymphocyte. (Note there are thousands of types of B-lymphocyte each with different receptors and the ability to make just one type of antibody.)
- ▼ Binding of antigen to antigen receptor activates the B-lymphocyte and causes it to divide by mitosis producing a clone of identical B-lymphocytes.
- ▼ Most of the B-lymphocytes turn into **plasma cells** and the rest turn into **memory cells**.
- ▼ The plasma cells begin to secrete specific antibodies against the foreign material concerned. Antibody molecules are secreted at a very high rate (up to 30 000 molecules per second).
- ▼ The antibodies attach to the antigens on the foreign material and lead to the destruction of it in one of three ways.
- ▼ By coating foreign cells or objects and causing them to stick together in such a way that they can then be engulfed by phagocytes (another type of white blood cell).
- ▼ By binding to the foreign cells or objects at sites which interfere with their activities. For example, by covering the protein coat of a virus and preventing it from attaching to host cells.
- ▼ By stimulating the release of other blood components to break up and destroy foreign cells.

Once the foreign material has been destroyed, the plasma cells eventually die and antibodies stop being secreted. But the memory cells remain in the lymph nodes and the circulation. If a subsequent infection with the same pathogen occurs then some of these will turn into plasma cells and start producing antibodies. This is the basis of **natural active immunity** to diseases and underlies the practice of immunisation or vaccination.

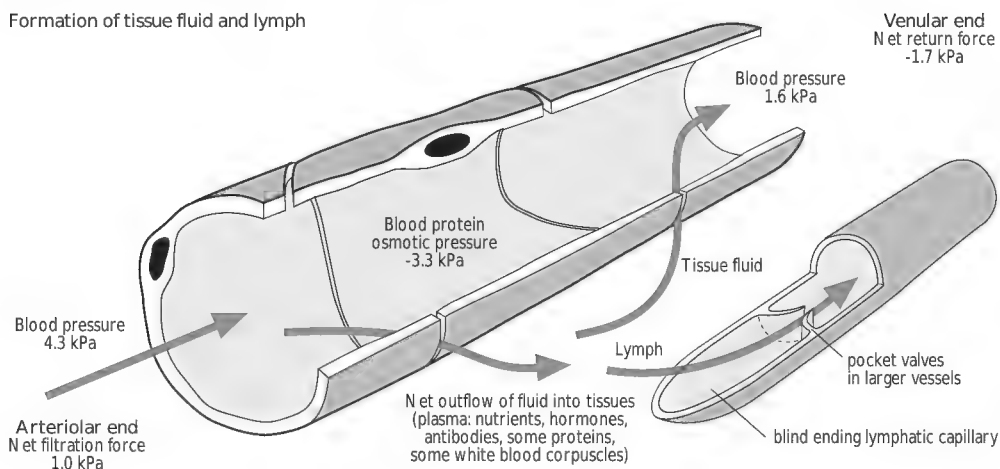
Platelets are white cell fragments, which have an important function in the clotting process.



Tissue fluid

Tissue fluid is formed when plasma, minus its proteins, is pushed out under pressure through the capillary walls to bathe the tissues. Depending on the degree of activity and health and fitness, most of the tissue fluid is reabsorbed back into the blood capillaries. Tissue fluid forms the internal environment of multicellular animals. It bathes each cell and is the medium for the exchange of materials between the individual cells and the blood system.

Formation of tissue fluid and lymph



◆ CHECKPOINT SUMMARY

- ◆ The hydrostatic pressure of the blood in the capillaries causes plasma minus its proteins to be forced through the thin walls of the capillaries.
- ◆ This fluid bathes all the tissues and is known as tissue fluid.
- ◆ It carries substances in solution from the blood to supply the tissues, e.g. oxygen, nutrients, hormones, antibodies etc; and drains waste products e.g. carbon dioxide away.
- ◆ Most of the tissue fluid is reabsorbed back into the capillaries as the hydrostatic pressure drops as the blood passes through the capillaries.
- ◆ Excess tissue fluid is drained away into blind ending lymphatic capillaries.
- ◆ Lymph is tissue fluid that has been drained into lymphatic capillaries, with lymphocytes added by lymph nodes which occur at intervals.
- ◆ Special lymph capillaries in the villi of the lining of the small intestine, known as lacteals, preferentially absorb and transport fats, so that lymph contains more fats than plasma.
- ◆ Eventually the lymph is returned to the general circulation in the major veins near to the heart.
- ◆ Movement of the lymph in the lymphatic system is maintained by the massaging effects of the muscles and breathing movements, and the one-way pocket valves; all features common to the veins of the circulatory system.

The transport of oxygen and carbon dioxide

Gas exchange occurs by diffusion between the air in the alveoli of the lungs and the blood in the capillaries. The relative amounts of oxygen and carbon dioxide in the air breathed in and out are measured as '**partial pressures**' in units of kiloPascals (kPa). (The continuous random movement of particles of a gas means that the particles will occasionally collide with each other and with the walls of any structure enclosing them within a space, thus exerting a pressure. The number of such collisions, and therefore the pressure, is proportional to the amount of substance present. In mixtures of gases, e.g. air, each substance exerts a partial pressure in that mixture proportional to the amount of that substance in the mixture. The partial pressure of a gas is a better measure of the amount of gas present than its percentage composition. Although the percentage of oxygen remains the same (21%) in air under different conditions, the amount of oxygen varies. At atmospheric pressures less than at sea level, e.g. at altitude, there is still 21% oxygen in air, but as the air is less dense there is a smaller amount of oxygen.)

As a result of its journey around the body, blood entering the capillaries of the alveoli has a lower oxygen and a higher carbon dioxide content (partial pressure) than the air in the alveoli. Therefore carbon dioxide diffuses out of the blood into the alveoli, and oxygen diffuses into the blood from the alveoli, each down their partial pressure gradients.

Roles of respiratory pigments (haemoglobin, fetal haemoglobin and myoglobin)

Oxygen absorbed into the blood in the alveolar capillaries combines with **haemoglobin** in the red blood cells to form **oxyhaemoglobin**. Each molecule of mammalian haemoglobin consists of four sub-units, each consisting of an iron-containing haem group combined with a protein globin part. Each sub-unit combines reversibly with one molecule of oxygen. Thus one molecule of haemoglobin can carry four molecules of oxygen. The formation of oxyhaemoglobin from deoxyhaemoglobin involves a physical holding of the oxygen by the haemoglobin sub-units as a result of their special 3-dimensional structure. In man each red blood cell contains about 300 000 000 molecules of haemoglobin. At rest and even during maximum exercise, at sea level, the haemoglobin in the blood leaving the lungs in healthy subjects is virtually saturated with oxygen. Therefore the capacity and functioning of the lungs is not normally the limiting factor in exercise. (The oxygen is easily displaced by carbon monoxide, which combines irreversibly with haemoglobin to form carboxyhaemoglobin. Major sources of carbon monoxide being smoking and car exhausts.)

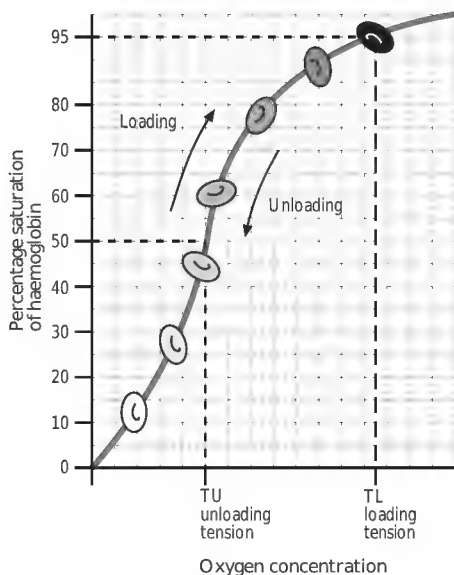
Gas exchange at the tissues is opposite to that at the lungs with oxygen being released and carbon dioxide taken up. Tissues vary widely in their demands for oxygen and in their production of carbon dioxide, particularly during exercise when the muscles become more active. The low oxygen partial pressure in the muscles during exercise increases the diffusion gradient between them and the red blood corpuscles, thus encouraging the dissociation of the oxyhaemoglobin and the release of oxygen in solution to diffuse to the tissues.

Fetal haemoglobin, found in the blood of the fetus developing in the uterus of the pregnant female, has a greater affinity (attraction) for oxygen than the adult haemoglobin of the mother, and thus can 'rob' it of oxygen, ensuring a good supply of oxygen to the developing fetus.

Myoglobin, found in skeletal muscle fibres, has a greater affinity (attraction) for oxygen than haemoglobin in the red blood corpuscles of the blood, and thus can 'rob' it of oxygen, ensuring a good supply of oxygen to the active muscles.

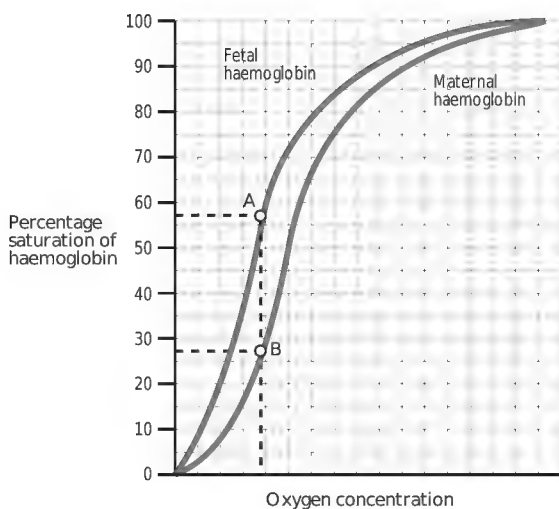
Some carbon dioxide is carried in the red blood cells in combination with haemoglobin as carbaminohaemoglobin. Some carbon dioxide is carried in the plasma in simple solution, but most is carried as hydrogen carbonate ions in the plasma. Carbon dioxide released as a waste product of cellular respiration enters the red blood cells where the enzyme carbonic anhydrase catalyses the formation of carbonic acid, which dissociates into hydrogen ions and hydrogen carbonate ions. The hydrogen carbonate ions enter the plasma to be carried to the lungs. The release of hydrogen carbonate ions into the plasma from the red blood corpuscles is balanced by the uptake by the red blood corpuscles of chloride ions from the plasma (the chloride shift). When the blood reaches the alveolar capillaries these events are reversed, hydrogen carbonate ions enter the red blood corpuscles, carbon dioxide is released to be breathed out, and chloride ions return to the plasma.

Haemoglobin association/dissociation curve

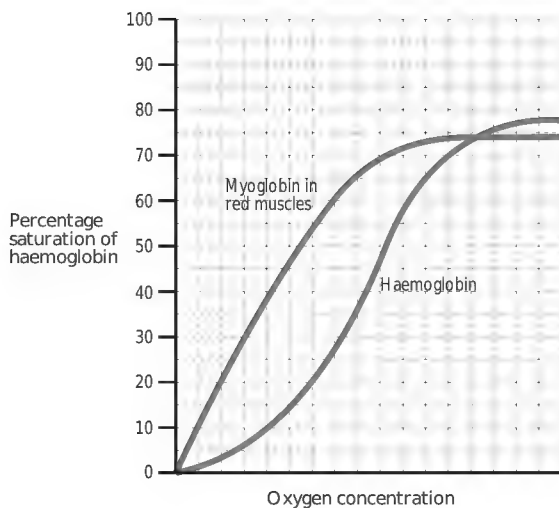


This basic type of curve is altered with differing conditions

Fetal and maternal haemoglobin

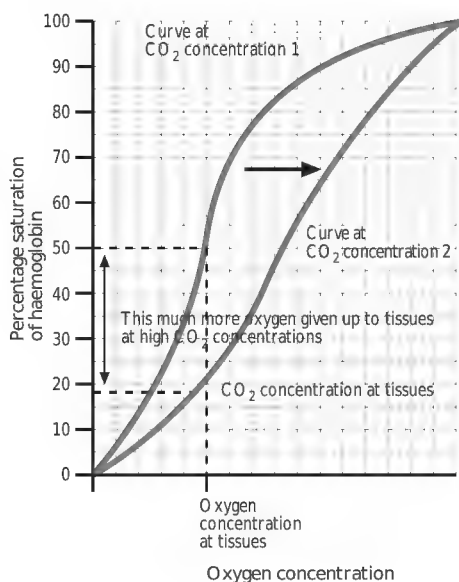


Myoglobin and haemoglobin



The effect of carbon dioxide on oxygen transport by haemoglobin (the Bohr Effect)

As has been described the red blood cells are involved in both oxygen and carbon dioxide exchanges and transport, each of which influence each other. At the tissues, the carbon dioxide, produced as a waste product of aerobic respiration in the mitochondria, diffuses in solution down its concentration gradient, from the high $p\text{CO}_2$ in the mitochondria to the lower $p\text{CO}_2$ in the blood. The greater the difference in $p\text{CO}_2$ the greater the amount of diffusion. The formation of carbonic acid (and lactic acid in anaerobic respiration) lowers the pH of the blood. Any increase in acidity (decrease in pH) and/or increase in temperature encourages oxyhaemoglobin to release its oxygen to the tissues. The way in which oxygen is held and released by haemoglobin at different partial pressures can be represented by an oxygen association/dissociation curve, and an increased tendency by oxyhaemoglobin to release its oxygen is shown by the oxygen association/dissociation curve shifting to the right. This effect is called the **Bohr shift** and its significance is that the more active the tissue (e.g muscle) the more carbon dioxide, lactic acid, and heat are produced and the more oxygen is released to that tissue.



◆ CHECKPOINT SUMMARY

- ◆ Reversible combination of haemoglobin and oxygen in the capillaries of the pulmonary circulation is a physical association.
- ◆ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor.
- ◆ Gas exchange at tissues is in effect the reverse of that at the lungs similarly explained in terms of diffusion gradients (partial pressure gradients).
- ◆ Bohr effect applies to conditions in tissues illustrates how conditions of increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ◆ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen. Note that the placental artery is some distance from the lungs of the mother and therefore not particularly well oxygenated.
- ◆ Myoglobin is a pigment found in red (endurance type) muscle fibres and has a greater affinity for oxygen than does haemoglobin, so that it is capable of loading up high with oxygen from relatively lower saturated haemoglobin. It acts as an intermediary between oxygen in the blood and the muscle fibres.
- ◆ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.

2B.3

Adaptations to the Environment

Content

- ▼ Species are adapted to survive in particular environmental conditions.
- ▼ Structural adaptation; the relationship of the external features of organisms to the physical characteristics of a specific habitat; xeromorphic adaptations in flowering plants; hydrophytes.
- ▼ The structural and physiological adaptations shown by invertebrates to the varying oxygen concentrations found in freshwater; including external gills, direct access to air, presence of respiratory pigment.

External features are related to the physical characteristics of a specific habitat

The external features of an organism always give clues to its habitat. For example, dark green waxy leaves indicate that a plant is adapted to survive periods of drought, thick fur on a mammal would suggest a cold environment, and gills, an aquatic existence. Other features reveal more about an organism's feeding or reproductive behaviour and suggest a particular life style, e.g. forward directed eyes are characteristic of carnivores, whilst the peacock's colourful feathers are connected with sexual display. The following examples show clearly how structural adaptations can give a survival advantage to organisms in particular habitats.

Adaptations of flowering plants to the availability of water

Xeromorphic adaptations

Plants growing in extreme conditions of water shortage show certain structural modifications which decrease the rate of water loss (transpiration) and allow them to survive periods of prolonged drought. Plants with these modifications of structure are known as **xeromorphic** and the plants themselves as **xerophytic plants**, or **xerophytes**. They can also show functional (physiological) adaptations e.g. the cytoplasm can survive almost complete desiccation, and the stomata may only open at night to prevent water loss in the heat of the day, as in the cacti.

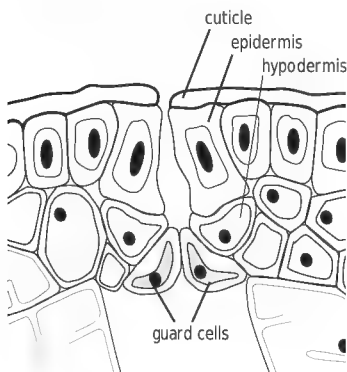
Xerophytes are typically found in dry regions and conditions of potentially high water loss. However, some plants with xeromorphic features are found in areas where there seems to be plenty of water, e.g. salt marshes, and wet heathlands and moors. These plants are living in conditions of physiological drought' where the water is unavailable to them for some reason. For example 'salty' conditions are more concentrated than the contents of the root cells, therefore the water potential gradient is from the root cells to the external solution i.e. out of the plant, instead of into the plant. (plants growing in 'salty' conditions are also known as halophytes).

Unit 2B: Exchange, Transport and Reproduction

There are many xeromorphic adaptations which conserve water and xerophytes can show any combination of these.

- ▼ Thickened waterproof cuticle reduces water loss through the surface of the leaf, especially on the upper surface of the leaf which is most exposed to air currents and heat absorption from sunlight, both of which increase the rate of evaporation of water from the leaf during transpiration; e.g. laurel leaves.
- ▼ The surface of the leaf may be 'hairy' (not true hairs) which protect the stomata from air currents which would otherwise increase transpiration e.g. 'Viper's Bugloss' (*Echium vulgare*).
- ▼ Stomata can be sunken in pits and grooves, which protect them from air currents, e.g. on pine 'needles'.
- ▼ Stomata can be reduced in number, especially on the upper surface of the leaves, where the exposure to the heat of the sun and air currents is the greatest, some e.g. laurel, have no stomata on the upper surface.
- ▼ Leaves can have a reduced surface area, which also reduces the number of stomata, e.g. pine 'needles'; and gorse and cacti where the leaves are reduced to spines and photosynthesis is carried out by the green stems.
- ▼ Leaf folding or rolling reduces water loss through the stomata by protecting them from air currents, and enclosing them in a zone of high humidity, e.g. sand dune grass (*Ammophila*), where the long ridged leaf rolls up along its length at times of excessive transpiration.
- ▼ Leaves can be succulent, with tissues where water can be stored for periods of drought, e.g. cacti.
- ▼ Cells of the leaves have mucilage and can withstand dehydration for longer periods than those of non-xerophytes (mesophytes).
- ▼ Leaf fall stops transpiration. Deciduous plants lose their leaves with the onset of winter in temperate regions, when the low temperatures inhibit water uptake by the roots, (you may have noticed that some of the xerophytes mentioned above (pine and laurel) are 'evergreens', i.e. they do not have to lose all their leaves in winter as they have a low transpiration rate). Some plants lose their leaves in dry periods for the same reason, and photosynthesis is carried out by their green stems e.g. broom.

Pine Needle Stomata

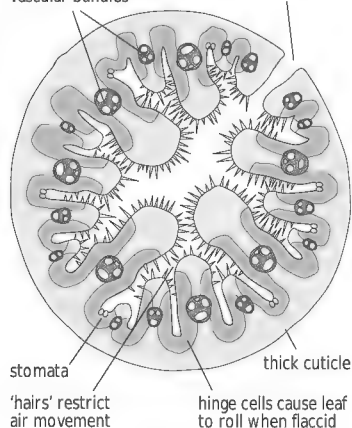


Marram Grass T.S.

Cross section leaf of *Ammophila* (sand-dune grass) or Marram Grass

edges of leaf almost meet to form narrow opening to dry air, opening alters through action of hinge cells

vascular bundles



Plants which live in fresh water or inhabit the margins of rivers and lakes are abundantly supplied with water but face other problems, the most serious of which is the lack of oxygen for their roots.

Remember that the uptake of minerals is an active process requiring high energy levels. In the absence of oxygen the roots will respire anaerobically but this can not be tolerated for long because they are soon poisoned by the ethanol released as a bi-product. Plants adapted to live in flooded or aquatic habitats show **hydrophytic** features and the plants are called **hydrophytes**. Rice is a hydrophyte. Its roots have an unusually high tolerance to ethanol and its seeds can germinate in oxygen starved soils. In common with other water adapted plants it also develops an interconnecting system of large air spaces linking the roots with the leaves and other parts above water. This specialised tissue is called **aerenchyma** and it allows the flooded roots to breathe.

The water lily (*Nymphaea*) floats freely on the surface of fresh water and shows more extreme hydrophytic features. Its stem is perforated by large air channels which supply oxygen to the roots. Stomata are present only on the upper surface of its huge leaves, and the spongy mesophyll layer has very large air spaces acting as buoyancy chambers.

Structural and physiological adaptations shown by invertebrates to varying oxygen concentrations found in fresh water

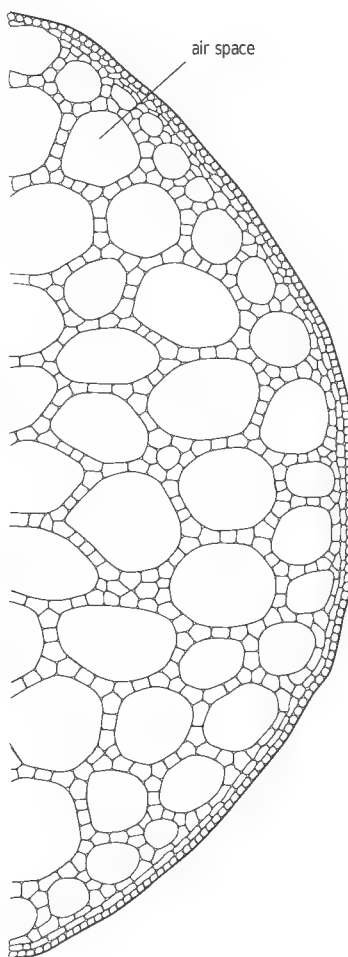
The amount of oxygen available to living organisms depends on its relative proportion in the surrounding medium. Air is a much more favourable environment than water in this respect because it contains 21% oxygen whilst the amount dissolved in water is much smaller. Furthermore, the amount of oxygen dissolved in water varies greatly according to the temperature, the warmer the water, the less oxygen it can contain.

Table of relation between temperature and oxygen content of water

Temperature °C	Volume of oxygen cm ³ /dm ³
0	10.29
10	8.02
15	7.72
20	6.57
30	5.57

This poses a problem for aquatic invertebrates. Small size is an advantage because, as you have seen, the smaller the body, the larger the surface area to volume ratio. The surface area to volume ratio may be increased by some modification of the body shape, for example, in the flattened body of the flatworms which allows sufficient diffusion of oxygen to occur all over the animal's surface. The most successful aquatic species, however, have become adapted in more specific ways to make best use of the available oxygen. This is particularly true of the arthropods (animals with jointed limbs and an exoskeleton), some examples of which are considered below.

T.S. water lily stem Aerenchyma



External gills

External gills are outgrowths from the body which increase the surface area for diffusion of gases between the water and the internal tissue fluids. These occur on different parts of the body in different organisms. Mayfly larvae have a row of paired gills on each side of the abdomen and, in poor oxygen conditions, e.g. shallow warm water, can be seen to undertake small 'press up' movements increasing the flow of water over the gills. Crustacea such as the fresh water shrimp have leaf like outgrowths on their limbs which are well supplied with 'blood' and are moved constantly to refresh the oxygen supply.

Direct access to air

A number of insect larvae, notably mosquito larvae have snorkel-like breathing tubes which enable them to breathe atmospheric air. This adaptation overcomes the problem of fluctuating oxygen supplies and allows them to survive in relatively warm and stagnant water. The diving beetle has a different strategy for air breathing. It has masses of fine hairs on the underside of its abdomen which trap air so that the animal has its own 'diving bell' supply of air when under water. Like terrestrial insects, these animals have a system of tracheal tubes which supply oxygen directly to all the body tissues and which connect to the external air supply by means of holes in the exoskeleton called spiracles. The spiracles may be closed to prevent the entry of water so that air is able to enter only at the site of the available oxygen supply.

Respiratory pigments

Respiratory pigments such as **haemoglobin** greatly increase the amount of oxygen available to body tissues. They take up oxygen from the external medium, releasing it readily to respiring tissues. It is a very significant advantage for aquatic invertebrates to possess respiratory pigments, particularly in the low oxygen conditions provided by warm water. Those which do not have respiratory pigments, for example the mayfly larvae are restricted to habitats which provide a good oxygen supply, e.g. fast flowing cold water. Tubifex worms and midge larvae possess haemoglobin pigments very similar to those of mammals and are abundant even in the most stagnant water. A number of crustacea, for example, crayfish and shrimps possess a blue pigment called **haemocyanin** with copper rather than iron forming the oxygen associating part of the pigment molecule.

◆ CHECKPOINT SUMMARY

- ◆ Hydrophytes are plants adapted to life in water.
- ◆ Flowering plants are secondarily aquatic, that is they have structural adaptations to a terrestrial life, which have become modified for life in water.
- ◆ Plants which live in fresh water or inhabit the margins of rivers and lakes lack oxygen for root respiration.
- ◆ The uptake of minerals is an active process requiring energy from aerobic respiration.
- ◆ Rice is a hydrophyte. Its roots have an unusually high tolerance to ethanol produced by anaerobic respiration and its seeds can germinate in oxygen starved soils.
- ◆ In common with other water adapted plants it also develops an interconnecting system of large air spaces (aerenchyma) linking the roots with the leaves above water.
- ◆ Invertebrates show structural and physiological adaptations to the varying oxygen concentrations found in fresh water; these include external gills, direct access to air, and the presence of respiratory pigments.
- ◆ External gills are outgrowths from the body which increase the surface area for diffusion of gases between the water and the internal tissue fluids. These occur on different parts of the body in different organisms.
- ◆ Direct access to air is found in a number of insect larvae, e.g. mosquito larvae have snorkel like breathing tubes which enable them to breathe atmospheric air. This adaptation allows them to survive in relatively warm and stagnant water.
- ◆ The diving beetle has masses of fine hairs on the underside of its abdomen which trap air so that the animal has its own 'diving bell'.
- ◆ Respiratory pigments such as haemoglobin greatly increase the amount of oxygen available to body tissues, releasing it readily to respiring tissues.
- ◆ A number of crustacea, for example, crayfish and shrimps possess a blue pigment called haemocyanin with copper rather than iron forming the oxygen associating part of the protein molecule.

2B.4

Sexual Reproduction

Content

Sexual reproduction

- ▼ Fusion of gametes, forming a zygote leading to genetic variation in offspring.
- ▼ Meiosis and its significance as the division of a diploid nucleus to give haploid nuclei; the behaviour of chromosomes during the first and second divisions of meiosis, including chiasmata formation.
- ▼ Haploid and diploid phases in the life cycles of organisms.

Reproduction in flowering plants

- ▼ The structure and functions of the principal parts of an insect-pollinated dicotyledonous flower and a grass.
- ▼ Pollination and the events leading to fertilisation.
- ▼ The adaptations related to insect and wind pollination.
- ▼ The significance of the mechanisms for ensuring cross-pollination; protandry, protogyny and dioecious plants.

Reproduction in humans

- ▼ The structure and functions of the male and female reproductive systems.
- ▼ The production of gametes in oogenesis and spermatogenesis.
- ▼ The events in the menstrual cycle; the roles of luteinising hormone, follicle-stimulating hormone, oestrogen, progesterone.
- ▼ The transfer of male gametes leading to fertilisation.
- ▼ Implantation; the functions of the placenta in relation to the development of the embryo.
- ▼ Birth and lactation, and the roles of oxytocin and prolactin.

SEXUAL REPRODUCTION

The fusion of gametes results in a diploid zygote

Sexual reproduction involves the fusion of the nuclei of the sex cells, or **gametes**, from the male and female sex organs, to form a **zygote** in a process of **fertilisation**. Individual organisms can be either single sexed (**dioecious**), or **hermaphrodite (monoecious)** bearing both male and female organs. Hermaphrodite organisms may be self-fertilising, or they may have outbreeding mechanisms which favour or compel cross fertilisation with another hermaphrodite individual.

During gamete production (**gametogenesis**) in animals, and in spore formation which precedes gamete production in plants, the number of chromosomes in the nucleus is halved in a process known as **meiosis**, so that normal gametes have half the normal number of chromosomes, that is they are **haploid**. A **diploid** zygote, which has twice the haploid number of chromosomes, is formed by fertilisation. Certain genetic 'mixing' events, which occur during meiosis, and the random fusion of the gametes result in genetic variation in the offspring which may be of adaptive advantage.

Meiosis

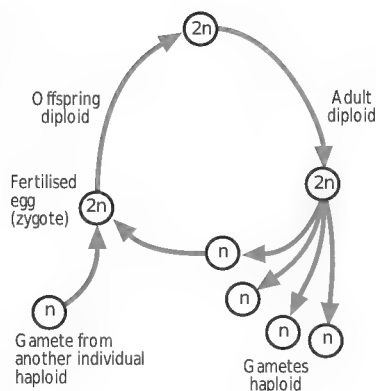
Meiosis is a special type of cell division called a **reduction division** in which the number of chromosomes is halved from the diploid to the haploid number. The mechanisms of cell division are very similar to that already described for mitosis.

Meiosis involves two divisions referred to as the first and second divisions (Meiosis I and Meiosis II). Remember that the nucleus of each cell contains two sets of chromosomes; one maternal, from the female gamete and one paternal, from the male gamete. As a result, each chromosome has a partner in the other set which carries genes for the same characteristics. Two such chromosomes are said to form a **homologous pair**.

During interphase, before nuclear division by meiosis starts, the DNA replicates

During prophase I the chromosomes are formed as double structures of a pair of **sister chromatids**. They then pair up with their homologous partners to form structures called **bivalents**. They twist around each other, and breaks occur in the chromatids. A break in one chromatid is matched by another in the corresponding non-sister chromatid. The broken ends rejoin with the ends of the non-sister chromatid resulting in a **crossing over** between non-sister chromatids. The homologous chromosomes begin to repel each other, and the points where crossing over has occurred serve to slow the repulsion and appear as a cross shape (**chiasma pleural chiasmata**). These crossing over points occur in a random fashion serving to reshuffle the genetic pack, mixing the DNA of the maternal and paternal chromosomes. Crossing over during meiosis is an important source of genetic variation in organisms which reproduce sexually.

Prophase I may take several days to complete. In metaphase I the chromosomes are pulled to the equator of the cell, held only by the junction points of the chiasmata. They line up on the equator at random, with maternal and paternal chromosomes on either side. During anaphase I the homologous chromosomes pull apart from each other, separating towards the opposite poles of the cell, the completion of which is known as telophase 1.



Crossing over, and the random alignment and separation of maternal and paternal chromosomes, prevents any gametes being formed from being replicas of gametes that formed the original cell undergoing meiosis, and therefore introduces genetic variation into the gametes.

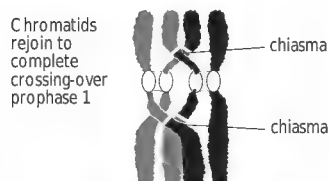
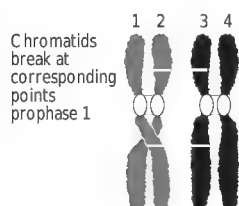
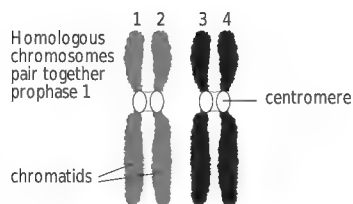
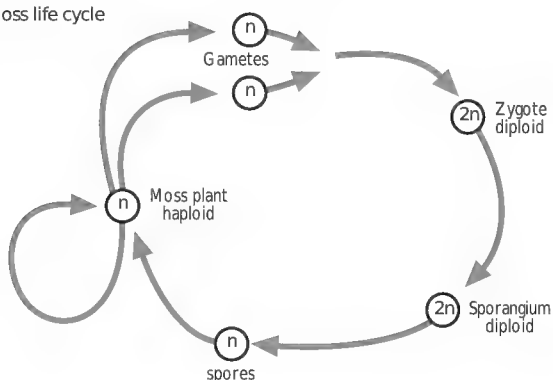
Two new spindles are formed at right angles to the first, one at each pole, and the chromosomes (each composed of two sister chromatids) move to the equator for a second metaphase (metaphase II). From here on, the events are similar to those of mitosis as the sister chromatids now move to opposite poles, i.e. anaphase II, and telophase II. Cytokinesis results in the formation of four new haploid daughter cells. Note that the result of meiosis is four cells (gametes) each containing half the original number of chromosomes with mixed up sections of maternal and paternal DNA sequences, as well as mixed up sets of maternal and paternal chromosomes.

The life cycle of plants involves haploid and diploid phases.

In all sexually reproducing plants there is an alternation of haploid and diploid phases in the life history. The cells of the haploid phase contain one set of chromosomes and the cells of the diploid phase contain two sets of chromosomes. This alternation is most clearly seen in the mosses in which a haploid, sexually-reproducing gamete producing plant (gametophyte) alternates with a diploid asexually-reproducing spore producing plant (sporophyte). Fertilisation is dependent upon the presence of a surface film of water. The gametophyte moss plant produces male gametes which swim in a surface film of water to the female organs. By contrast the process of spore dispersal depends on dry wind currents so it is important that the sporophyte lifts the spore cases so that they are exposed to air currents.

Although the life cycle of Flowering plants is so different from that of mosses, their reproductive structures and the sequence of events leading up to fertilisation reflects this alternation between haploid and diploid stages. In Flowering plants the main plant is the diploid sporophyte generation, and the haploid gametophyte generation is reduced to a few cells and nuclei within the pollen grains and ovum.

Moss life cycle



Separated chromosomes after completing meiosis 1



Separated chromatids after completing meiosis 2



Usually 2 or 3 cross-overs affect each chromosome pair. Note cross-overs can occur between 1&3; 1&4; 2&3; 2&4, but not 1&2 or 3&4

◆ CHECKPOINT SUMMARY

- ◆ Offspring result from the fusion of gametes, forming a zygote.
- ◆ This fusion of gametes involves various genetic mixing events and therefore leads to genetic variation in offspring.
- ◆ These genetic mixing events include events in the nuclear division (meiosis) involved in the production of gametes, and in the random fusion of gametic nuclei from different sexes.
- ◆ Meiosis is a reduction division in which the diploid number of chromosomes (two sets) is reduced to the haploid (one set).
- ◆ In the first phase of meiosis (Meiosis I) the two sets of chromosomes pair up, so that chromosomes occur in homologous pairs. Each chromosome is duplicated into two chromatids, so one pair of chromosomes is made up of four chromatids.
- ◆ The homologous chromosomes of a pair entwine, one chromatid of each pair breaks and rejoins with the broken chromatid of the other pair, in a process known as genetic recombination or crossing over.
- ◆ The chiasmata align on the equator of the nuclear spindle apparatus (NSA), before the homologous chromosomes repel each other to opposite poles.
- ◆ Cross overs are visible under the light microscope and are known as chiasmata (Greek for crosses), they result in the exchange of genes (alleles) between homologous chromosomes.
- ◆ Either chromosome of each pair can go to a particular pole, resulting in mixing of the original sets (independent assortment).
- ◆ Two daughter nuclei are thus formed, each with one (haploid) set of chromosomes, with each chromosome composed of two chromatids.
- ◆ The second phase of meiosis (Meiosis II) involves the centromeres of the chromosomes aligning on the equator of a each of two new NSA formed at right angles to the first.
- ◆ The chromatids then repel each other to form four new haploid nuclei.
- ◆ Animals and plants are typically diploid and have haploid gametes, but mosses have haploid plant bodies, produce gametes without meiosis which fuse to form a diploid sporophyte which produces haploid spores by meiosis to produce new haploid moss plants.

Reproduction in flowering plants

Flowers are the reproductive organs of plants in which gametes are produced and fertilisation occurs. Most flowers are bisexual (hermaphrodite) bearing both male and female organs, the stamens and carpels. Where separate male and female flowers occur on the same plant it is said to be monoecious. In a few cases, the stamens and carpels are found on separate male and female plants (dioecious). Dioecious plants have the obvious advantage of enforced out breeding, but rely entirely on external agents for the transfer of gametes. The structure of flowers is closely related to their method of pollination, with the two main agents of pollination being insects and the wind.

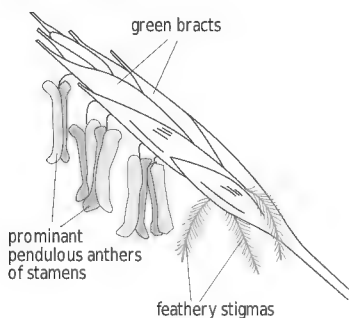
Insect pollinated flowers typically have various combinations of the following features.

- ▼ Coloured petals and other flower parts, white flowers often have UV light reflecting strips visible to insects.
- ▼ Nectaries containing sweet nectar.
- ▼ Scent glands.
- ▼ Various structural modifications to guide insects to the correct positions to deliver and/or pick up pollen.
- ▼ Compared to wind pollinated plants, relatively small amounts of large sticky pollen grains.
- ▼ Compared to wind pollinated plants, relatively small stigmas.

Wind pollinated flowers typically have various combinations of the following features.

- ▼ Reduced petals and other flower parts.
- ▼ No nectaries.
- ▼ No scent glands.
- ▼ Compared to insect pollinated plants, relatively large amounts of small light smooth pollen grains produced by dangling stamens exposed to air currents.
- ▼ Compared to insect pollinated plants, relatively large feathery stigmas exposed to wind currents.
- ▼ Flowers often produced before leaves emerge.

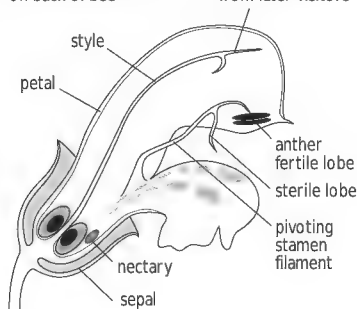
Wind pollinated flower



Insect pollinated flower

Bee pushes sterile lobe and fertile lobe pivots down to deposit pollen on back of bee

Stigma projects at a later stage and picks up pollen from later visitors



Pollination

Pollination is the process by which pollen is transferred from the anther lobes of the stamen to the stigma of the carpel. Flowers may be self-pollinating or cross-pollinating.

Self-pollination occurs when the stigma receives pollen from the stamens of the same flower. This is only possible in hermaphrodite flowers when the stamens and carpels mature at the same time. The stamens are often arranged so that the pollen can fall on to the stigma(s). Many self-pollinating flowers, e.g. the garden pea, self-pollinate in the bud stage before the flower opens. Indeed, in some the flower never opens and is eventually destroyed by the development of the fruit.

In **cross-pollination** the stigma receives pollen from the stamens of a different flower, which may either be on the same or on a different plant. It must be noted however that if a flower is cross pollinated by pollen from a flower on the same plant then, like self-pollination, this is still a case of **in-breeding**. It is only cross-pollination between flowers on different plants that results in true genetic **out-breeding**. There are a variety of devices which favour cross-pollination, but only some of these ensure out-breeding, that is cross-pollination between flowers on different plants.

Devices preventing self-pollination and favouring cross-pollination in hermaphrodite flowers

Hermaphrodite flowers can have their stamens and stigmas maturing at different times. In some plants, the anthers mature first (**protandry**) for example, *Geranium* spp., whilst in others (less commonly) the carpels mature first (**protogyny**), for example *Luzula* (woodrush). In many cases, however, there is an 'overlap' period when both anthers and stigmas are mature during which self-pollination could occur if the flowers have not been cross-pollinated for some reason.

Hermaphrodite flowers frequently have special arrangements of their parts to prevent self-pollination. For example, the iris has a flap on its style which prevents pollen on the back of a withdrawing insect from coming into contact with the stigma; similarly the viola has an arrangement by which the stigma is exposed to pollen on the incoming insect but is covered as the insect leaves.

Devices preventing in-breeding and favouring out-breeding

If a species has separate male plants and female plants, that is if it is dioecious, then clearly out-breeding must always occur. Some species, despite having hermaphrodite flowers, encourage out-breeding by means of genetically determined **incompatibility** by which pollen will not grow normally on the stigmas and styles of flowers on the same plant. In some cases the incompatibility is complete and pollen on the stigma of the same flower or on a different flower on the same plant never develops correctly, so that in-breeding never occurs. In others it is only partial. In these cases the pollen tube grows down the style of flowers on the same plant more slowly than pollen from another plant, but can eventually lead to fertilisation of the ovule. Partial incompatibility allows for in-breeding should out-breeding not occur.

◆ CHECKPOINT SUMMARY

- ◆ The structure of flowers is adapted to the mode of pollination, the two main ones being insect and wind pollination.
- ◆ Pollination is the transfer of pollen from the pollen sacs of the male stamens to the stigma of the female carpel.
- ◆ Insect pollinated flowers typically have bright coloured floral parts (especially petals), nectar, and scent to attract insects.
- ◆ Petals may be modified as landing platforms for insects, stamens are designed to deposit pollen on visiting insects, and stigmas are arranged to have pollen grains deposited on them from visiting insects.
- ◆ Wind pollinated flowers have reduced floral parts, no nectar, prominent hanging stamens exposing, and large 'hairy' stigmas collecting, pollen carried on air currents.
- ◆ Wind pollinated plants typically flower before the emergence of the leaves in the spring of temperate climates.
- ◆ Various arrangements exist to reduce the possibility of pollen reaching the stigma of the same plant.
- ◆ Protandry (development of the stamens before the stigma of the carpel).
- ◆ Protogyny (development of the stigma before the stamens).
- ◆ Dioecious species with separate male and female plants.
- ◆ Pollen germinates on a compatible stigma, and the pollen tube grows down through the style, to reach the egg cell (ovum) nucleus in the ovule.
- ◆ The pollen tube nucleus degenerates, and the generative nucleus divides into two male gametic nuclei.
- ◆ One of the male gametic nuclei fuses with the ovum nucleus to form the diploid zygote nucleus, and the other fuses with the two polar nuclei to form the triploid endosperm nucleus.
- ◆ This double fertilisation is unique to flowering plants.

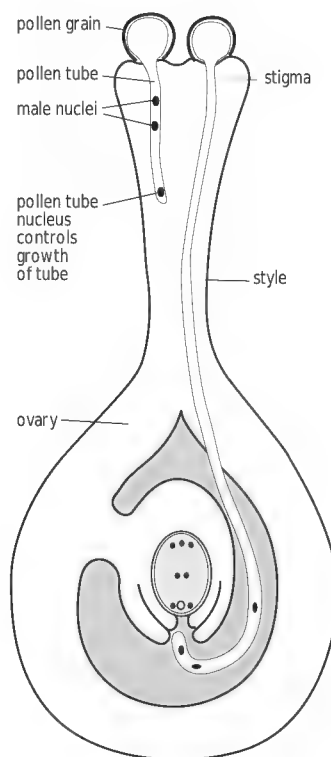
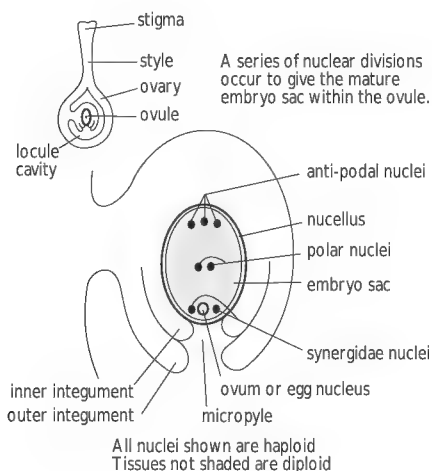
Fertilisation

At an early stage in the development of the ovule, whilst the flower is still in bud, nuclear divisions, in which the chromosome number is halved by meiosis, occur to produce a haploid cell which divides and grows into a small structure called the **embryo sac**. This contains eight nuclei, only three of which are directly involved in the reproductive process, namely, the **egg nucleus** and the two **polar nuclei**. The embryo sac is surrounded by a nutrient-rich tissue called the **nucellus**, located within the ovule, the whole structure being surrounded by a double wall (inner and outer **integuments**). A small gap in the wall (**micropyle**) allows the entry of the pollen tube.

When a pollen grain lands on a receptive stigma, it germinates forming a pollen tube which grows through the tissues of the style and ovary until it reaches the ovule, absorbing energy-rich nutrients along the way. Growth of the pollen tube is under the control of the pollen tube nucleus, whilst the generative nucleus is carried along at the advancing tip. Before it reaches its destination, the generative nucleus divides to form two male gamete nuclei.

Fertilisation in flowering plants is a double event involving both of the male nuclei. One of these fuses with the egg nucleus to form a diploid zygote which will divide and grow into the plant embryo. The other fuses with both polar nuclei to form a triploid (triple fusion) nucleus.

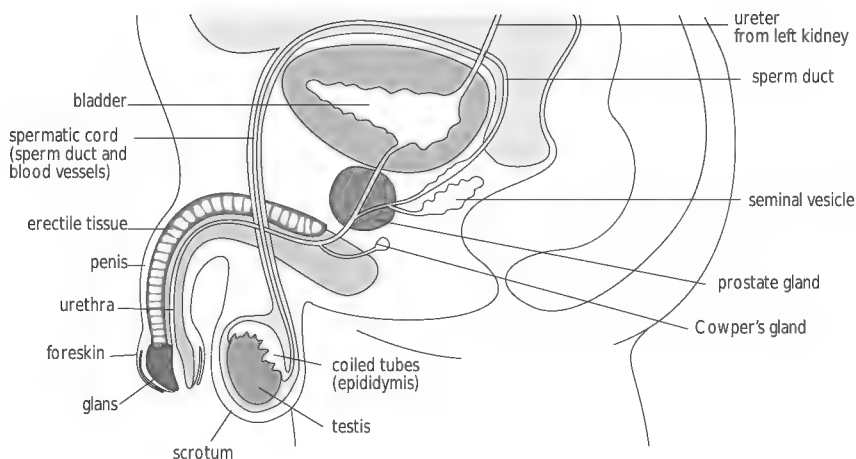
After fertilisation, the ovule undergoes a number of changes to become a seed. The zygote develops into the embryo of the new plant; the triple fusion nucleus develops into the endosperm (food store) in endospermous seeds (mainly members of the grass family e.g. wheat and rice) and in others it degenerates; the integuments develop into the seed coat (testa). The wall of the ovary develops into the fruit.



REPRODUCTION IN HUMANS

Structure and function of the male reproductive system

The male reproductive system



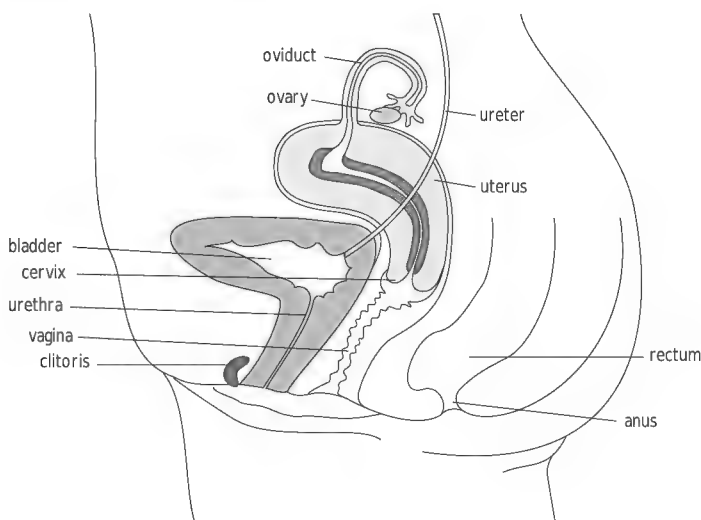
The male gamete producing organs (**testes**) have two functions. Firstly, the production of haploid male gametes (sperm) capable of fertilising an ovum and so passing on the male's genes into a new generation. Secondly, the production of male hormones, particularly testosterone. This allows the development of the secondary sexual characteristics of the male and is also needed for sperm production and sexual activity. Both functions are performed in the **semeniferous tubules** which are packed into lobules inside each testis. **Spermatogenesis** (the production of sperm discussed later) occurs in the walls of the tubules whilst testosterone is secreted by cells in between the tubules (interstitial cells). The testes lie outside the body in the **scrotum**. The function of this is to keep the testes slightly cooler than body temperature (about 35°C) for optimal sperm production.

The remaining components of the reproductive system are all concerned with moving sperm from the testes to the **urethra** and into the female reproductive tract during sexual intercourse. The sperm are moved from the seminiferous tubules and transported to the **epididymis**, a long coiled tube where fluid is reabsorbed from the sperm and chemicals secreted which allow sperm to complete their maturation and develop the ability to swim. From here sperm are moved to the sperm ducts (vas deferens), which lead into the urethra just below the exit from the bladder.

In order to perform their functions, sperm are mixed with a variety of secretions to form **semen** before they leave the body during ejaculation (see below). The paired **seminal vesicles** secrete a watery alkaline fluid containing sugars (e.g. fructose) for nourishing the sperm. Mucus is also secreted. The **prostate gland** and **Cowper's glands** also secrete alkaline fluid and mucus. The alkaline fluid helps to neutralise any traces of urine present in the urethra and to neutralise the acid environment of the vagina, so providing more suitable conditions for the sperm to function.

The **penis** is used to convey sperm into the reproductive tract of the female during sexual intercourse. It contains **erectile tissue** and a central tube, the urethra through which semen from the sperm ducts pass. At other times this tube carries urine from the bladder. A system of **sphincter muscles** closes the exit from the **bladder** during sexual activity.

The female reproductive system



The female gamete producing organs (ovaries) lie inside the abdomen. As in the male these have two functions: the production of haploid female gametes (ova) containing genetic information from the female; and the production of female hormones, particularly oestrogen and progesterone.

These hormones control the development of secondary sexual characteristics and, along with hormones from the pituitary gland, control the events of the menstrual cycle.

Close to the border of each ovary is the **oviduct**. The oviducts are narrow tubes whose function is to transport ova released from the ovary to the uterus. The oviducts aid the movement of ova to uterus in two main ways. Firstly they have a fringed funnel which help to 'catch' the ova and guide them into the oviduct. Secondly they are lined with ciliated epithelial cells which beat and so move the ovum along towards the uterus. Fertilisation usually takes place in the oviduct.

The **uterus** is a muscular organ about 7 x 5 cm in size in a non-pregnant woman whose function is to house a developing embryo. Its wall consists of three layers: an outer covering; a thick middle layer of smooth muscle (the **myometrium**); and the inner **endometrium** containing a dense network of blood vessels and glands. The characteristics of the endometrium vary during the menstrual cycle as discussed below. During pregnancy the uterus can expand to up to 10 times its normal size.

The **cervix** or neck of the uterus is a ring of smooth muscle containing mucus secreting cells which help to provide optimum conditions for sperm survival at around the time of ovulation. The cervix is normally tightly closed but during birth will dilate to allow the baby's to emerge head first.

The **vagina** is a short muscular tube which receives the penis during sexual intercourse. It is lined with epithelial cells secreting vaginal fluids. Like the cervix it must stretch to several times its normal size during birth.

The external female genitalia or **vulva** consists of the **labia majora** and **labia minora** which surround the vaginal opening, opening of the **urethra** and the **clitoris**, a small erectile structure. The clitoris is similar in structure to the penis. Stimulation of the clitoris may result in orgasm.

Glands within the vulva secrete mucus to lubricate the penis during sexual intercourse.

Spermatogenesis and oogenesis

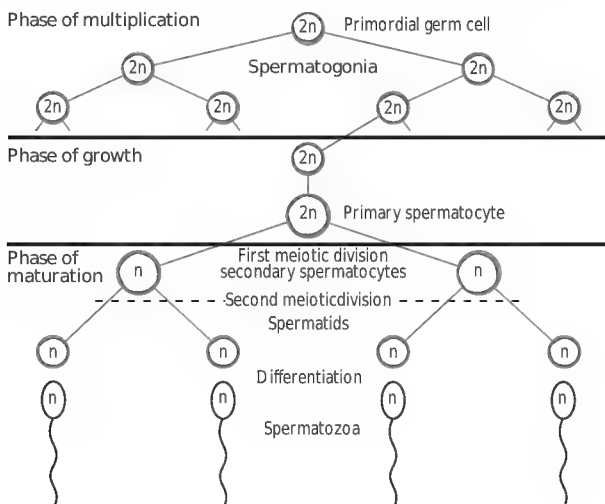
Spermatogenesis is the term used to describe the production of male gametes (sperm). Oogenesis is the production of female gametes (ova). These two processes share many essential similarities, such as the central role of meiosis in creating haploid gametes. There are however several differences in the timing and organisation of the processes. These can help to explain why adult males produce several million small sperm per day whilst women produce just one large, mature 'egg cell' per month.

Spermatogenesis

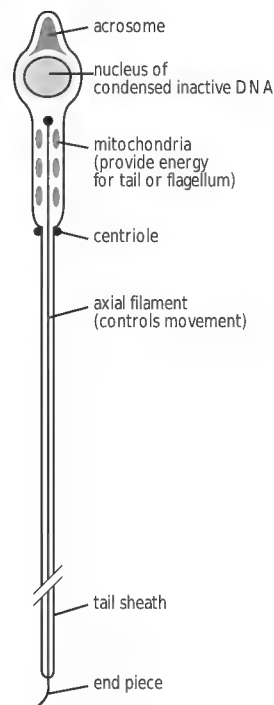
Sperm are produced in the seminiferous tubules within the testes of the adult male. The process of spermatogenesis is initiated by the hormone testosterone at the time of puberty. Epithelial germ cells in the outer layer of the seminiferous tubule divide by mitosis to form a population of diploid **spermatogonia**. These divide by mitosis and grow into **primary spermatocytes**. Each primary spermatocyte undergoes meiosis, forming two haploid **secondary spermatocytes** in Meiosis I and four **spermatids** in Meiosis II. In the final stage each spermatid develops from a round cell into a fully functional sperm cell (**spermatozoa**). This complete process of spermatogenesis takes about 70 days.

As spermatogenesis progresses, the developing sperm cells move towards the lumen of the seminiferous tubule into which they will eventually be released. The cells are attached to large **Sertoli cells** (nurse cells) until maturity. These cells provide oxygen and nutrients and remove waste products. They also play an essential role in remodelling the spermatid to form a sperm cell.

A mature sperm is approximately 20 μm in length and 2.5 μm in diameter, the smallest cell in the human body. It consists of a **head**, containing a haploid nucleus and a membrane bound sac of enzymes at the tip, (the **acrosome**), a **middle piece** containing many mitochondria to provide energy for swimming, and a **tail** containing microtubules.



Spermatozoon



Oogenesis

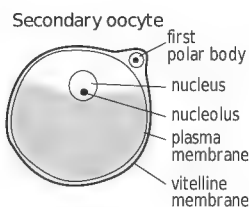
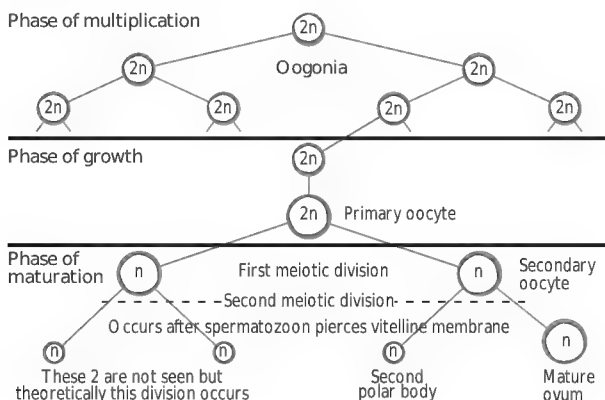
Unlike spermatogenesis, oogenesis does not begin at puberty, but in fetal life. Oogenesis begins in the germinal epithelium of the ovary where germ cells divide by mitosis to form **oogonia**. Further mitosis and growth of these cells produces **primary oocytes**. These cells begin Meiosis I but are halted during prophase. A layer of granular cells develops around each primary oocyte forming a **primary follicle**. Several million of these follicles are present at birth of which only a fraction will complete their development into gametes during the reproductive life span of the woman. From puberty onwards one follicle per month will complete its development into an **ovarian follicle** (Graafian follicle) containing a female gamete (secondary oocyte). The stages in the development of one follicle and the primary oocyte within it can be summarised as follows:

The primary oocyte inside the follicle enlarges whilst its surrounding granular cells increase in number, and are surrounded by an outer layer of cells (the **theca**) derived from the tissue of the ovary. Under the influence of **follicle stimulating hormone** (FSH) and **luteinising hormone** (LH) the follicle continues to grow into a secondary follicle, developing a central space filled with fluid secreted by the granular cells. Further enlargement, under the influence of oestrogen secreted by the granular cells, produces a mature Graafian follicle up to 1cm in diameter.

Meanwhile, inside the follicle the primary oocyte completes its first meiotic division, forming a haploid **secondary oocyte** and a small functionless **polar body** (containing the other half of the chromosomes). The second meiotic division begins but is halted in metaphase. At this point, mid way through the menstrual cycle, the Graafian follicle bursts to release the secondary oocyte. Meiosis II is not completed until the moment of fertilisation when a second polar body is formed. Strictly speaking the term **ovum** should not be used until that point.

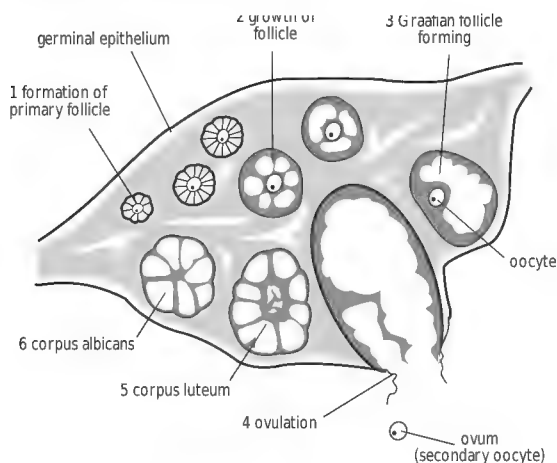
The secondary oocyte which is released at ovulation is a large cell, about 140 μm in diameter. It contains a haploid nucleus and a large quantity of grainy cytoplasm. It is surrounded by a jelly like layer, the **zona pellucida**. The ovarian (Graafian) follicle after releasing the secondary oocyte becomes the **corpus luteum** which has an important role in the secretion of progesterone and oestrogen.

All of the changes described above occur during a single menstrual cycle. Further details of the menstrual cycle are given below.



Polar bodies take no part in reproduction and disappear, therefore only one functional cell is produced from the primary oocyte.

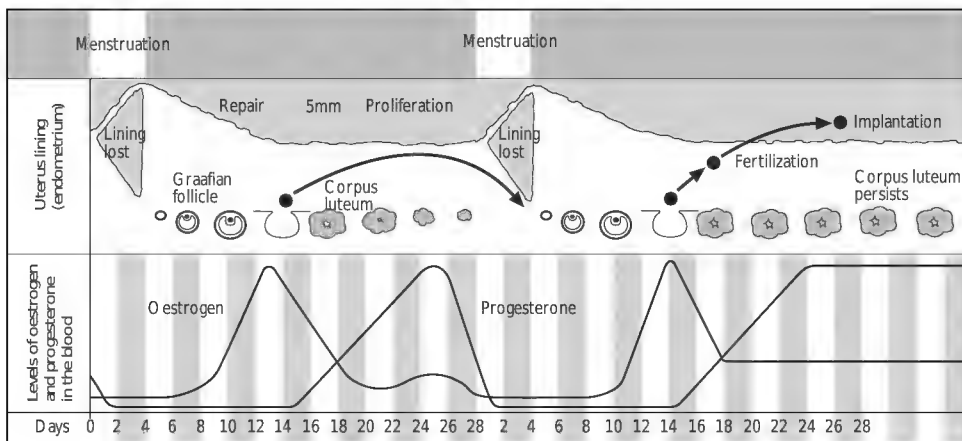
Mammalian ovary section



The menstrual cycle

Between puberty (average age 12) and the menopause (average age 45) human females experience regular sexual cycles, known as menstrual cycles. Each cycle is approximately 28 days long and involves a series of changes within the ovary and uterus. These can be considered as two separate but closely linked cycles: the **ovarian cycle** which is concerned with the development and release of an 'egg cell' around the mid point of the cycle, offering the chance of fertilisation if mating occurs; and the **uterine cycle** which is concerned with the development of the endometrium (uterus lining) to ensure the highest chance of implantation of a fertilised ovum or zygote.

Unless pregnancy occurs, one menstrual cycle will follow directly on from the next. (Therefore when interpreting graphs of the cycle note that day 28 is followed by day 1.)



The events of the menstrual cycle

The menstrual cycle relies on interactions between four main hormones: the ovarian hormones oestrogen and progesterone and the pituitary hormones Follicle Stimulating Hormone (FSH), and Luteinising hormone (LH). A further hormone, from the hypothalamus, Gonadotrophin Releasing Hormone (GnRH) is also involved. The events of the menstrual cycle are summarised below:

- ▼ Release of GnRH from the hypothalamus causes FSH to be released from the anterior pituitary. FSH travels in the bloodstream to the ovaries where it stimulates the development of several follicles (primary oocytes). One or more of these will eventually mature into an ovarian (Graafian) follicle containing the secondary oocyte.
- ▼ FSH stimulates the production of oestrogen from the follicles within the ovaries. This oestrogen in turn stimulates the growth of the endometrium, replacing cells lost during the previous menstrual period. At this point oestrogen has a negative feedback effect on FSH, reducing its production.
- ▼ Oestrogen levels increase until the mid point of the cycle when they bring about a peak of LH production from the anterior pituitary causing ovulation (the release of the secondary oocyte from the Graafian Follicle). A small peak of FSH production also occurs at the time of ovulation.
- ▼ LH causes the Graafian Follicle to develop into a corpus luteum which begins to secrete progesterone and oestrogen.
- ▼ Progesterone stimulates further development of the endometrium, in particular an increase in the density of spiral arteries and an increase in the secretion of mucus and fluid from glands in the endometrium. This is sometimes known as the secretory phase and its function is to prepare the uterus in case the newly released secondary oocyte ('egg' cell) is fertilised.
- ▼ The other function of progesterone is to inhibit the production of both FSH and LH and hence the development of further follicles. This is an example of negative feedback.
- ▼ If fertilisation does not occur, the corpus luteum degenerates and secretion of progesterone and oestrogen falls. This fall causes the uterine blood vessels to rupture and the uterus lining to degenerate and pass out of the body via the vagina. This is known as menstruation or the menstrual period and lasts for 4-5 days. Decline in progesterone levels causes the inhibition of FSH and LH to be removed and a new cycle can begin. Note that a new cycle begins whilst menstruation is still occurring.
- ▼ If fertilisation does occur then the corpus luteum does not degenerate but continues to secrete progesterone and oestrogen, maintaining the uterus lining and preventing further follicles from developing. After about 12 weeks of pregnancy in humans and corresponding times in other mammals the developing placenta takes over this hormonal (endocrine) role.

◆ CHECKPOINT SUMMARY

- ◆ The male reproductive system consists of the testes which produce spermatozoa by meiosis.
- ◆ A system of tubes and erectile tissue transfer them to the female reproductive tract.
- ◆ Accessory glands are important in secreting substances essential for successful fertilisation of the female.
- ◆ The female system consists of ovaries which release egg cells (ova) into the abdominal cavity, from where they are swept down the oviducts by ciliated epithelium, into the uterus where they may or not be implanted.
- ◆ The uterus connects to the exterior by the vagina.
- ◆ The ova are produced (oogenesis) by meiosis in the germinal epithelium of the ovaries. Of the products of meiotic nuclear division, one accumulates all the cytoplasm to form the relatively large ovum, and the others are reduced to polar bodies.
- ◆ Spermatozoa are produced (spermatogenesis) by meiosis in the germinal epithelium of the testes. The four products of meiosis all develop into spermatozoa.
- ◆ The menstrual cycle is a monthly version of the ovarian cycle found in all mammals.
- ◆ A sequence of hormonal secretions from the brain, pituitary gland, and the ovaries themselves, coordinated by negative feedback loops control the events of the cycle.
- ◆ Luteinising hormone stimulates the release of the an ovum from an ovarian follicle, and the development of the corpus luteum. In the male it stimulates the secretion of testosterone by the testes.
- ◆ Follicle stimulating hormone initiates the development and growth of the ovarian follicles, and stimulates the ovary to secrete oestrogen. In males it stimulates spermatogenesis by the testes.
- ◆ Oestrogen stimulates the development of the primary and secondary sexual characteristics, the development of the uterus lining in the first half of the menstrual cycle.
- ◆ Progesterone stimulates the secretory phase of the uterus in the second half of the cycle, and maintains pregnancy whilst suppressing further ovulation.

The transfer of male gametes and fertilisation

If fertilisation is to occur then male gametes must come into contact with the female gametes. Under natural circumstances male gametes are transferred into the reproductive tract of the female via the penis during sexual intercourse.

For sexual intercourse to occur, the male's penis must first become erect. This occurs following sexual stimulation and involves an increase of blood flow into the spongy erectile tissue of the penis. Movement of the erect penis inside the vagina during intercourse stimulates the sensory cells at the tip of the penis. A series of stages, co-ordinated by the sympathetic nervous system then follow, eventually leading to ejaculation: the release of semen containing sperm into the vagina. These stages include:

- ▼ contraction of the involuntary muscle lining the sperm duct and epididymis so forcing the sperm towards the urethra;
- ▼ contraction of the seminal vesicles, Cowper's and prostate glands which add their secretions to the sperm;
- ▼ closure of the bladder sphincter muscle; and reflex contractions of the muscles surrounding the urethra, forcing the semen out of the penis and high into the vagina of the female. Ejaculation is accompanied by the intense sensation of orgasm.

A single ejaculation can contain several hundred million sperm. Once in the vagina these sperm acquire the ability to swim and begin their journey through the cervix (first aligning themselves with long chains of mucus), across the uterus and up into the oviducts. The speed with which they may reach the oviducts suggests that muscular movements of the uterus and oviduct may in fact be more important than swimming at this stage. It has been suggested that chemicals called prostaglandins contained in seminal fluid could bring about this effect. If ovulation has occurred within 24 hours prior to this, a secondary oocyte should be present in one of the oviducts and it is here that fertilisation may take place.

Fertilisation

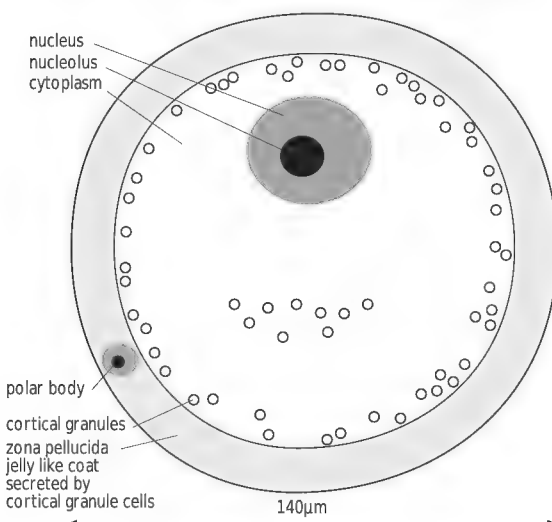
Fertilisation is the process by which the haploid nucleus of a single sperm cell fuses with the haploid nucleus of a single ovum creating a diploid zygote.

Before a sperm can fertilise the secondary oocyte it must undergo a process known as **capacitation** where it is 'primed' for the process by the acid environment of the uterus. The main feature of this involves changes in the cell membrane of the sperm in the region around the acrosome vesicle. Firstly the membrane is weakened and becomes more permeable, and the acrosome membrane fuses with the cell membrane.

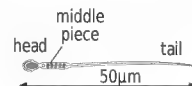
When a sperm comes into contact with the zona pellucida of a secondary oocyte the acrosome reaction occurs. This involves the acrosome splitting open and releasing the lytic enzymes contained within it. These begin to digest the zona pellucida, allowing the sperm to move through it to reach the cell membrane of the secondary oocyte. When it reaches the membrane it fuses with it and its head enters the cytoplasm. The tail is left behind. Entry of the sperm stimulates the nucleus of the secondary oocyte to complete its second meiotic division so that it can fuse with the nucleus of the sperm.

One of the surprising things about fertilisation is the mechanism which allows just one single sperm to penetrate the secondary oocyte when several hundred or thousand sperms are surrounding this cell. As the sperm enters the secondary oocyte a number of changes occur which result in the layer surrounding the egg cell (zona pellucida) becoming impermeable to other sperm.

Human female gamete (secondary oocyte) just before fertilisation



Human male gamete just before fertilisation



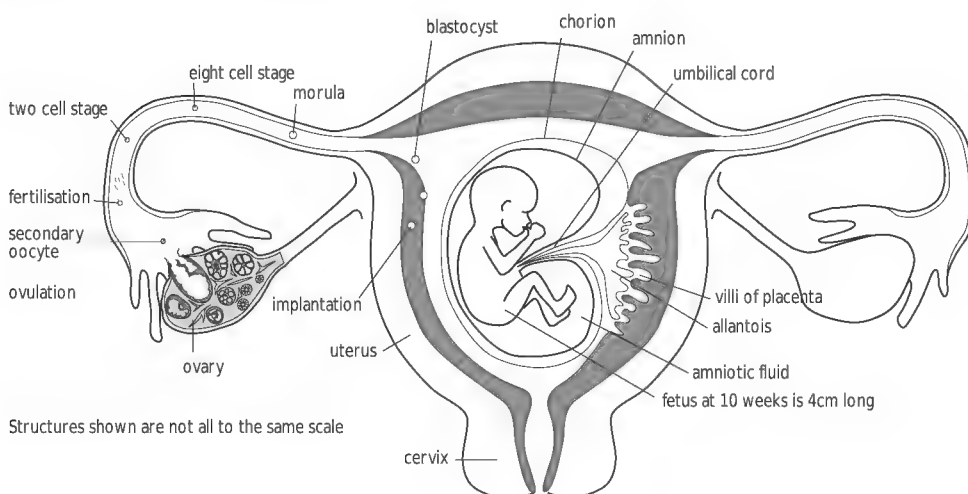
140µm is smaller than the smallest dot you can make with a fine ball point pen

Implantation

Following fertilisation the zygote undergoes cell division by mitosis forming a small ball of identical cells within a few days. Gradually the cells start to differentiate (become specialised for different tasks) and the ball of cells becomes a hollow sphere filled with fluid (blastocyst). The outer wall of the blastocyst is made of cells called **trophoblasts** which will form the villi which grow into the wall of the uterus at implantation. A small mass of cells inside this layer will form the embryo. As these changes occur, the zygote moves slowly down the oviduct and towards the uterus where it must implant in the uterine wall if further development is to take place. The cells secrete a hormone called **human chorionic gonadotrophin (hCG)** which maintains the corpus luteum, ensuring that it continues to secrete oestrogen and progesterone. (The presence of hCG in the urine is detected in a 'pregnancy test'.)

When the blastocyst arrives in the uterus it is still contained within the zona pellucida. As this breaks down the trophoblastic cells of the blastocyst come into contact with the endometrium of the uterus. They begin to invade the endometrium, secreting digestive enzymes and growing into the maternal tissues. This process, which results in the blastocyst becoming embedded in the endometrium, is known as implantation. It occurs as early as seven days after fertilisation.

Implantation is the first stage in the crucial association between maternal and fetal tissues and circulation which form the basis of mammalian development. As the trophoblastic cells become embedded in the endometrium of the uterus they differentiate to form finger like projections which penetrate deep into the endometrium. These are the **chorionic villi**. Enzymes secreted by the cells of the villi digest the walls of the spiral arteries and veins within the endometrium and create blood filled spaces around each villus. From here the maternal blood nutrients and oxygen diffuse into the villi and are delivered to the cells of the blastocyst. Carbon dioxide and other waste materials diffuse out of the blastocyst and into the maternal blood down their concentration gradients. The efficiency of these exchanges is improved by the large surface area of chorionic villi.



Over the following weeks rapid growth and development of both the chorionic region and the embryo occur. Within three to four weeks of fertilisation blood is circulating through embryo and villi. This improves the efficiency of exchange.

The structure and function of the placenta

The placenta is fully formed 12 weeks after fertilisation. On the maternal side it consists of projections of the endometrium between which lie a series of blood filled spaces. Blood from the maternal arteries enters the spaces where exchange is performed and then returns to the circulation in the maternal veins. On the fetal side, chorionic villi project into the blood filled spaces. Each villus contains branches of the umbilical artery and vein which form a dense network of capillaries. These join up to form the **umbilical artery** and **veins** which run through the umbilical cord to the embryo (at this stage called the fetus). It should be noted that the blood of mother and fetus are kept entirely separate. This helps to regulate exchanges between mother and fetus, protects the fetus from the effects of high maternal blood pressure which would damage its small blood vessels, prevents possible immune reactions which might occur if the fetus was of different blood group to the mother, and prevents the entry of mature female hormones which would be dangerous even for a female fetus.

The placenta has two main roles in relation to the development of the human embryo and fetus. Firstly it is the organ of exchange between mother and fetus, supplying the fetus with nutrients and oxygen and removing carbon dioxide and urea. Antibodies are also supplied to the fetus which protect it from infections in the first months of life. Secondly it is an endocrine organ producing several hormones throughout the gestation period (development time before birth).

In order to perform its exchange roles efficiently the placenta must provides a large surface area for exchange of nutrients and gases; a thin yet selectively permeable barrier between maternal and fetal blood; and a steep concentration gradient for each substance in the appropriate direction.

A large surface area is provided by the numerous villi and the highly branched capillaries within the villi between the fetal blood contained in vessels and the maternal blood in the large blood filled spaces of the placenta. Maternal and fetal blood are separated by just a few layers of cells creating a short diffusion distance. Small molecules (eg. oxygen, carbon dioxide, urea, water) move across by simple diffusion whilst amino acids and glucose cross by facilitated diffusion. Some vitamins and minerals move by active transport.

Oxygen, glucose, amino acids and other substances required by the fetus need to be at a much higher concentration in the maternal blood than they are in the fetal blood for efficient diffusion to occur. Similarly, carbon dioxide and urea must be at a low concentration in the maternal blood if they are to diffuse out of the fetal blood and be removed. Favourable gradients are maintained by the fact that the fetus has a small volume of blood but a high rate of blood flow whilst the mother has a slower rate of blood flow but a larger volume of blood in the spaces of the placenta, and by an overall counter-current system of blood flow in which the maternal and fetal blood flow in opposite directions maintaining steeper diffusion gradients. Just before birth about 10% of the mothers blood flows through the placenta on each circuit of the body, aiding rapid exchanges.

Hormones secreted by the placenta

The placenta secretes three main hormones:

- ▼ Human chorionic gonadotrophin (hCG)
- ▼ Progesterone
- ▼ Oestrogen.

Each has specific roles relating to fetal development and/or maternal changes associated with pregnancy, birth and lactation (milk production).

hCG is secreted in only small amounts by the placenta but is thought to have roles in suppressing FSH and LH from the pituitary and in stimulating development of some fetal systems.

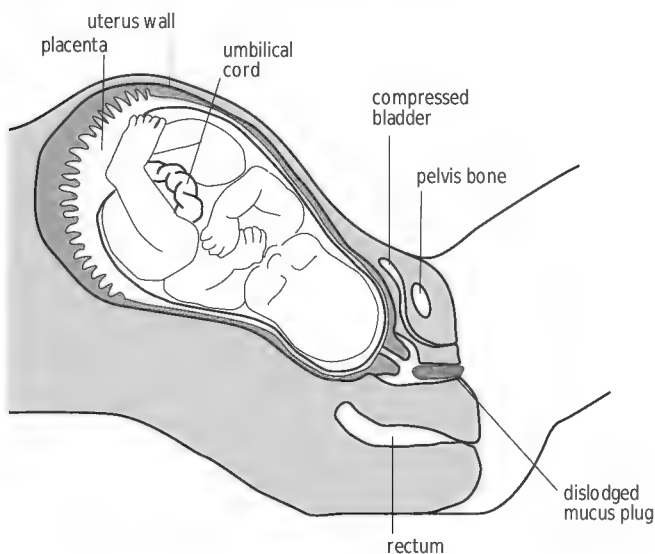
Progesterone is secreted in relatively large quantities (250-350mg/day). High levels prevent shedding of the endometrium, inhibit ovulation and may aid breast development.

Oestrogen is necessary for the maintenance of pregnancy (perhaps through inhibiting FSH) and is thought to be involved in preparing the body for birth and in breast development.

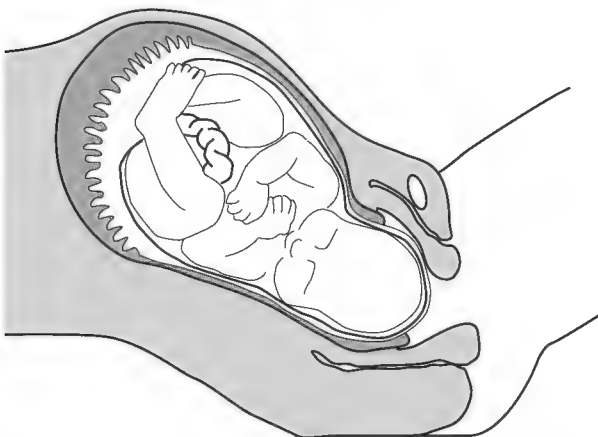
Birth

Approximately 38 weeks after fertilisation the fetus is ready to be born. At around this time the level of the hormone progesterone decreases rapidly and the level of oestrogen increases. The effect of this is to make the uterus wall more susceptible to the effects of **oxytocin**, a hormone produced by the posterior pituitary gland, which causes contraction of the muscle layer of the uterus (the myometrium). The exact signals which trigger these changes in hormone levels and hence initiate the birth process are not clear but are thought to involve a mixture of physical and hormonal signals from both mother and fetus.

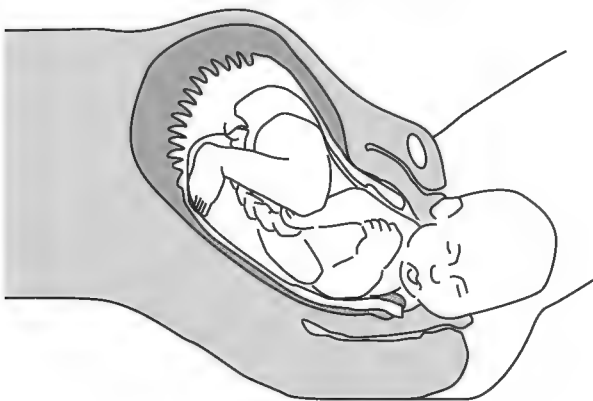
The birth process can be divided into several stages.



In the **first stage**, which may last 12 hours or more, the uterus begins to contract and the cervix begins to dilate. During, or sometimes before the main contractions begin the amniotic sac bursts and the fluid is released via the vagina. A plug of mucus which blocks the cervix during pregnancy also detaches and passes out of the vagina. Over time the force and frequency of the contractions increases under the control of oxytocin and they spread out through the muscle fibres of the uterus from top to bottom, gradually pushing the fetus downwards toward the cervix. By the end of this stage the cervix has dilated to about 10cm in diameter, wide enough to allow the fetal head to 'engage' and then pass through.



The **second stage** involves the actual birth of the baby which is pushed out of the uterus, through the cervix and down the vagina. The majority of babies are born head first, having moved into this position in the uterus in the weeks leading up to birth. The head and shoulders of the baby are the widest part so once these have passed through the cervix the rest of the body, still attached to the placenta via the umbilical cord, follows more easily. Once it emerges the baby begins to breathe. Since it no longer requires an oxygen supply via the placenta the umbilical cord is cut and tied/clipped.





The third stage involves the loss of the placenta from the body. Final contractions allow this structure to detach itself from the uterus wall and pass out of the vagina. Although a large loss of blood may be expected, muscle fibres around the blood vessels contract to limit this.

Lactation

In its first nine months of life before birth the fetus obtains all its nutritional requirements via the placenta. After birth it must ingest milk produced by the mammary glands of the mother and delivered via the nipple. Suckling begins soon after birth and a new born baby may spend several hours per day engaged in feeding. For the first four months of life babies are rarely given any other food or drink, and in many cultures breast feeding may continue to supplement other foods for several years. The production of milk is known as lactation.

Milk, is a watery fluid containing the sugar lactose along with fat, and proteins, some vitamins and minerals. It is produced in the milk glands of the breast and its secretion is stimulated by suckling. The substances contained in milk are easily digested in and absorbed from the baby's gut.

Milk production is controlled by the interaction of several hormones. During pregnancy, the hormones oestrogen and progesterone stimulate the development of breast tissue containing milk glands and milk ducts. However, milk is not produced and released at this stage as progesterone and oestrogen inhibit another hormone, **prolactin** which is also required. The fall in levels of progesterone and oestrogen after birth removes this inhibition and allows prolactin from the anterior pituitary gland to act on the breast tissue. It stimulates the milk glands of the breast which are lined with milk producing epithelial cells to secrete milk.

Milk is not released until the milk ejection reflex is initiated by the sucking action of a baby. The following steps are involved:

- ▼ nerve impulses from sensory receptors in the nipple are sent to the hypothalamus; this stimulates the posterior pituitary gland to produce **oxytocin**;

Unit 2B: Exchange, Transport and Reproduction

- ▼ oxytocin acts on the involuntary muscle around the milk glands which contract, forcing milk through the ducts and out of the nipple.
- ▼ At the same time, suckling also causes the release of prolactin from the anterior pituitary, hence maintaining milk production.

By these feedback mechanisms it can be seen that continued milk production and release will only continue if a baby is suckling.

◆ CHECKPOINT SUMMARY

- ◆ Spermatozoa are ejaculated by the erect penis in the region of the cervix at the entry to the uterus.
- ◆ Peristaltic movements of the female tract and the motility of the spermatozoa themselves result in movement up the oviducts.
- ◆ If these events coincide with the release of one or more ova, fertilisation can occur high up in the oviduct.
- ◆ The fertilised egg immediately enters into mitotic cell division, and is a hollow ball of cells (blastocyst) by the time the uterus is reached.
- ◆ The blastocyst becomes implanted in the pre-prepared lining of the uterus, and secretes gonadotrophic hormone.
- ◆ The lining of the uterus is maintained and the menstrual cycle is suspended.
- ◆ The placenta develops and secretes progesterone which helps to maintain the pregnancy and suppress further ovulation.
- ◆ The placenta attaches the fetus to the uterine wall and has a large surface area for the exchange of materials with the maternal circulation, e.g. the absorption of oxygen and nutrients, and the elimination of waste products, e.g. urea and carbon dioxide.
- ◆ The efficiency of exchanges is increased by extensive breakdown of tissue in the placenta and the uterus wall, reducing the diffusion distance between the two circulations.
- ◆ At full term the fluid filled amnion which surrounds the fetus bursts, the fluid lubricates the system and birth is initiated.
- ◆ The hormone oxytocin secreted by the posterior pituitary lobe produces powerful contractions of the uterus, induces lactation, and stimulates the ejection of milk during suckling.
- ◆ The hormone prolactin secreted by the anterior pituitary lobe stimulates lactation.

Biology (Human)



Unit 2H

Exchange Transport and Reproduction in Humans

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Exchange, Transport and Reproduction in Humans

Contents

2H.1

Exchange with the Environment

1

- ▼ Exchange surfaces
- ▼ Breathing
- ▼ Gas exchange
- ▼ Digestion and absorption

2H.2

Transport of Materials

17

- ▼ Circulation
- ▼ The circulatory system
- ▼ Blood and body fluids

2H.3

Human Ecology

37

- ▼ Adaptations to extreme environments
- ▼ Extremes of temperature
- ▼ High altitude

2H.4

Human Reproduction & Development

51

- ▼ Reproduction
- ▼ Development

2H.1

Exchange with the Environment

Contents

Exchange surfaces

- ▼ The features of exchange surfaces which aid passive and active transport. The histology of epithelia revealed by light and electron microscopy; squamous epithelium (alveolus), cuboidal epithelium (nephron), columnar epithelium (ileum).

Breathing

- ▼ The structure of the breathing system and the mechanism of ventilation.
- ▼ The principle of a spirometer and interpretation of spirometer data.
- ▼ The effects of physical activity and increase in carbon dioxide concentration on breathing rate and volume.

Gas exchange

- ▼ The characteristics of alveoli as surfaces involved in gas exchange.
- ▼ The effects of smoking on ventilation and gas exchange including the effects in relation to pregnancy.
- ▼ The origin of carbon monoxide from car exhausts and tobacco smoke and its effects.

Digestion and absorption

- ▼ The structure of the alimentary canal in relation to digestion and absorption.
- ▼ Mastication and movement of food along the gut.
- ▼ The histology of the ileum wall.
- ▼ The sources and effects of secretions concerned with the digestion of carbohydrates.

Exchanges with the environment

All living cells obtain oxygen and nutrients from the fluid environment which surrounds them, and excrete waste substances into this environment. The individual cells of the human body are surrounded by a fluid medium called **tissue fluid** or extracellular fluid, with which they exchange materials. This is referred to as the '**internal environment**' and specialised systems are present for exchange to occur between the internal and the external environment.

Passive and active transport

The exchange of respiratory gases, oxygen and carbon dioxide occurs through **passive diffusion**, the rate of which is dependent upon the concentration gradient between the external environment and the exchange surface and the distance travelled. In general it conforms to the following equation, known as Fick's law.

$$\text{Rate of diffusion} = \frac{\text{surface area} \times \text{difference in concentration}}{\text{thickness of the exchange surface}}$$

In principle, the greater the surface area, the greater the concentration difference, and the thinner the separating layers, the more rapid the diffusion.

Active transport is involved in the uptake of some nutrients and the exchange of inorganic ions with the environment. Active transport occurs against the prevailing diffusion gradients (from low concentration to high concentration) via special carriers in the cell surface membranes, and is dependent upon a supply of energy in the form of ATP from respiration in the cells.

The structure of epithelial tissues

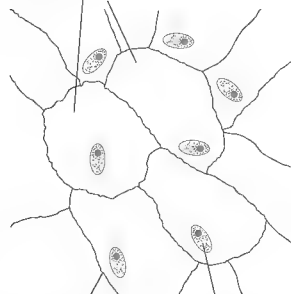
Epithelial tissues are lining tissues which cover both external and internal surfaces, and typically form sheets of large surface area but of thin cross-section. The cells are held together by an intercellular cement rich in calcium ions, which are important in cell adhesion, and by tight junctions between adjacent membranes. At their base the cells are fixed to a basement membrane. They have one free surface which is often highly specialised with, for example, microvilli or cilia.

The alveoli of the lungs form the surface for gas exchange and they are constructed from very flattened cells called **squamous epithelium** which serve to minimise the distance between the air and the blood.

A different kind of epithelium, called **cuboidal epithelium**, lines the part of the kidney tubule (nephron) where glucose and other solutes are actively reabsorbed into the blood. These cells are provided with a great number of mitochondria to supply their energy needs and the surface area of their outer plasma membrane is increased dramatically by the presence of a fringe of microvilli.

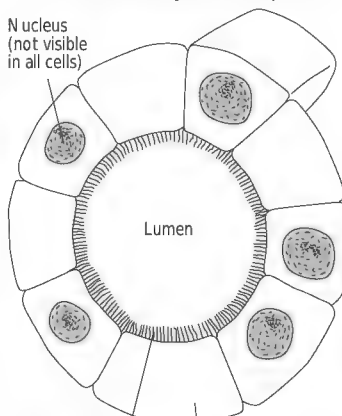
The uptake of digested nutrients from the gut into the blood also depends upon active transport and the epithelial cells lining the gut are specialised in a similar way for this purpose, being equipped with numerous mitochondria and microvilli. These cells are elongated and are called **columnar epithelium**.

Surface view of simple squamous epithelium
thin plate-like squamous cells



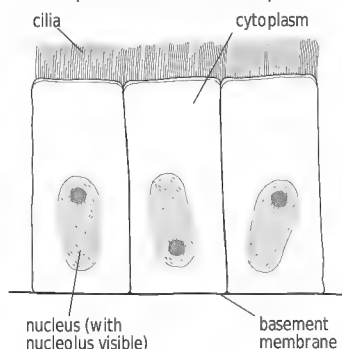
cell outline maybe wavy or smooth
nucleus (with nucleolus visible)
In section squamous cells look like slender rods thickened where the nucleus is located

Proximal convoluted tubule (cross section) from cortex of kidney-cuboidal epithelium



Striated (brush) border of microvilli
Cuboidal epithelial cells

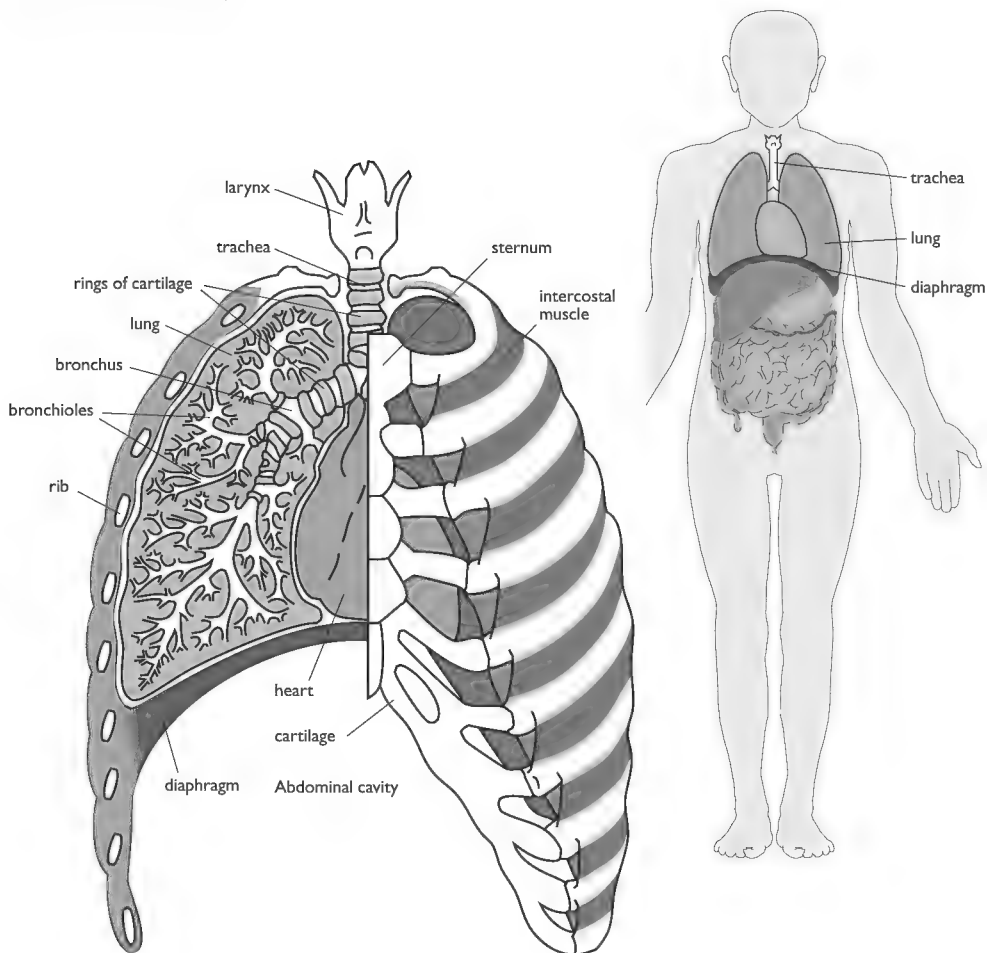
T.S. simple ciliated columnar epithelium



BREATHING

The structure of the breathing system

The organs of gas exchange in mammals are the lungs which, together with the heart, fill all the available space in the air tight **thoracic (chest) cavity** bounded by the ribs and the muscular sheet known as the **diaphragm**.



Air passes into a series of tubes which make up the respiratory system having first been warmed and moistened in the nasal cavity. The **trachea, bronchi and bronchioles** form a system of branching air tubes referred to as the 'bronchial tree'. The wall of the trachea and bronchi are composed of four layers. These are the inner **epithelial** layer, a **submucosa** layer consisting of connective tissue, elastic fibres and mucous glands, a layer of **involuntary muscle** and **cartilage**, and a tough outer coat of **connective tissue**. Bronchioles differ in that they have less cartilage and no mucous glands.

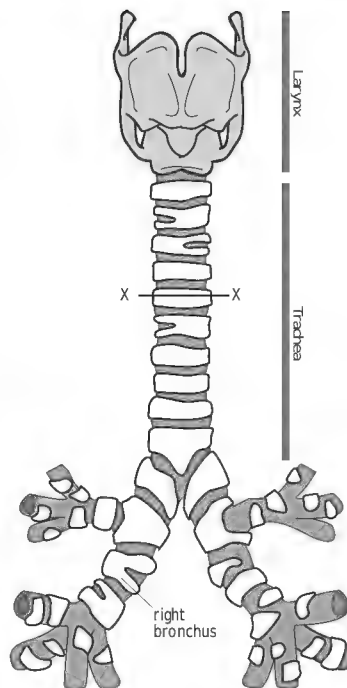
Unit 2H: Exchange, Transport and Reproduction in Humans

Cartilage supports the trachea and bronchi and prevents their collapse. In the trachea the cartilage forms C-shaped rings which are arranged so that the open ends of the C are at the back of the tube, facing towards the spine. These support the tube and keep it open during inspiration (breathing in). Between the ends of the Cs at the posterior (back) of the trachea, involuntary muscle completes the tube. The incomplete nature of these 'rings' of cartilage allow a degree of compression as a result of the expansion of the oesophagus when swallowing food. In the bronchi the cartilage does not form rings but instead forms plates within the smooth muscle layer to strengthen the tubes.

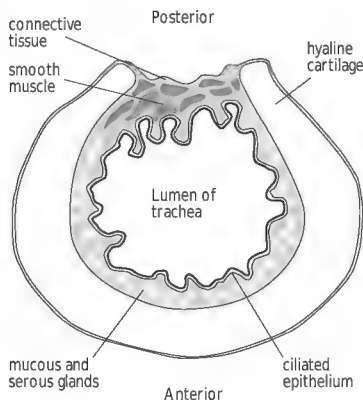
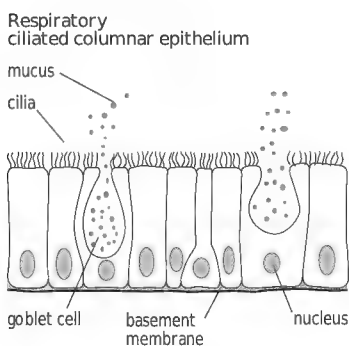
Involuntary muscle found in the trachea, bronchi and bronchioles also helps maintain the shape of the tubes and prevents collapse of the airways. The involuntary muscle receives nerve impulses from the autonomic nervous system which can regulate the diameter of the tubes. This is significant in diseases like asthma and anaphylaxis where constriction of the bronchioles occurs restricting air flow.

The lining of the trachea, bronchi and bronchioles consists of ciliated columnar epithelium; this has ciliated cells and goblet cells. At the very end of the bronchioles, close to the alveoli only ciliated cells remain.

Ciliated epithelial cells have a protective function as they work in a co-ordinated fashion sweeping the mucous coat of the air passages, which contains small inhaled particles such as dust, towards the pharynx (throat and mouth) where they can be removed by the cough reflex. This prevents such particles from entering the alveoli and interfering with gaseous exchange. **Goblet cells** which are interspersed amongst the ciliated cells in the trachea and bronchi, are responsible for producing and secreting mucus within the respiratory tract. The layer of mucus which lines the airways traps dust and bacteria. It may also play a role in humidifying inhaled air.



Section X - X



The mechanism of ventilation

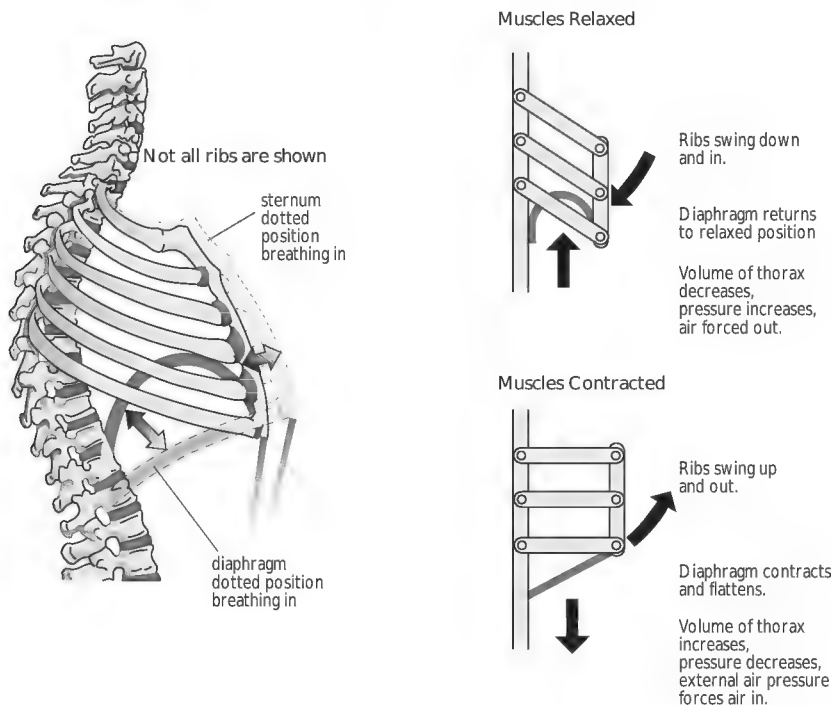
Ventilation in mammals is achieved by the breathing movements of the **intercostal muscles** of the ribs and the muscular **diaphragm**; which are controlled by the autonomic and voluntary nervous systems.

During **inspiration** (breathing in) the external intercostal muscles contract pulling the ribs upwards and outwards. At the same time the diaphragm contracts, moving downwards. Both movements increase the volume of the thorax, reducing the pressure in the thorax below atmospheric pressure causing air to enter, inflating the lungs. At rest, **expiration** (breathing out) does not involve active muscle contractions, but depends upon the elasticity of the tissues of the lungs and thorax. The intercostal muscles relax, allowing the rib cage to move downwards and inwards, and the diaphragm relaxes and regains its domed shape. The volume of the thorax is reduced, pressure increased and air forced out of the lungs. During forced breathing, for example as a result of exercise or in speech, expiration is active, with the internal intercostal muscles and abdominal muscles contracting to increase the pressure within the thorax.

Friction between the lungs and the inner surface of the wall of the thorax is reduced by the **pleural fluid** which lies between the two pleural membranes that surround the lungs, and which keeps the lungs sticking to the inside of the wall of the thorax, preventing their collapse.

Breathing movements thus result in certain volumes of air passing into and out of the lungs.

Ventilation of the lungs involves the rate and the depth of breathing.



MEASUREMENT OF BREATHING: THE SPIROMETER

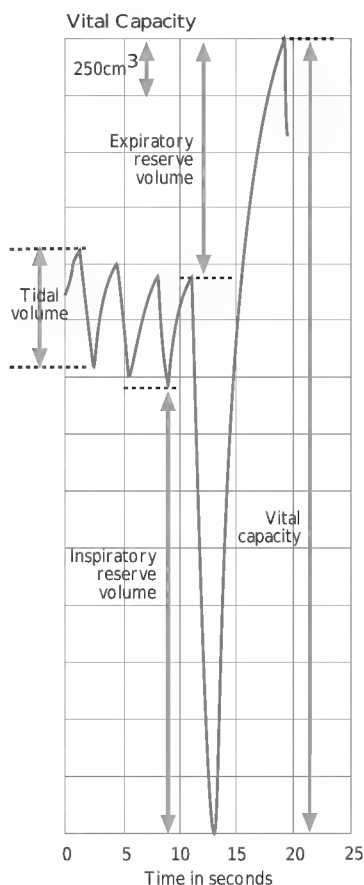
Tidal volume

This is the volume of air breathed in and out in a single breath in a single breathing cycle. During normal quiet breathing at rest, a healthy, active mature male of average height would have a tidal volume of about 500 cm^3 . Of this 500 cm^3 , about 350 cm^3 reaches the alveoli where gaseous exchange occurs. The remaining 150 cm^3 fills the pharynx, larynx, trachea, bronchi, and bronchioles, which compared to the alveoli are poorly supplied with blood capillaries, so that very little, if any, gaseous exchange occurs here. This space where no gaseous exchange occurs is known as the **anatomical dead space**, and the air that occupies it as the **dead air volume**. The volume of air that remains largely stationary during tidal breathing is known as **stationary air**.

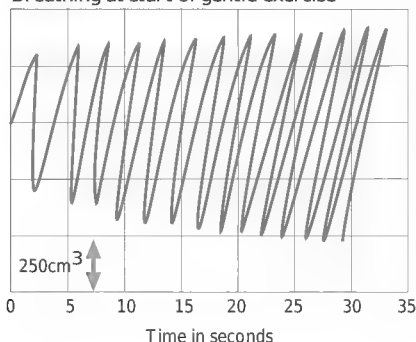
By breathing in as deeply as possible an extra volume of air, in addition to the tidal volume and the stationary air, can be taken into the lungs. This is the **inspiratory reserve volume** and can be up to 2000 cm^3 . By breathing out as forcibly as possible after returning to normal breathing, it is possible to expel some of the stationary air in addition to the tidal volume. This is known as the **expiratory reserve volume** and can be up to 1500 cm^3 . However the lungs cannot be emptied entirely, otherwise they would collapse, and this remaining air is known as the **residual volume** which can be up to 1500 cm^3 .

The sum of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume is known as the **vital capacity**. The vital capacity represents the maximum total amount of air that can be moved into and out of the lungs by one inhalation and one exhalation, and is about 3000 cm^3 - 4000 cm^3 in the average adult male.

These volumes and the lung capacities vary considerably between individuals. They are generally smaller in females than in males, due to smaller average body size in females, and correlate closely with body size, height and surface area up to age 25. Smoking and associated lung diseases can considerably reduce lung volumes and capacities.



Breathing at start of gentle exercise



This trace does not show the total lung volume and residual volume, which are not easily measured. With increasing age the residual volume increases from about 20% of the total lung volume to more than 30%.

The effects of physical activity on breathing rate and volume

Breathing movements are under nervous control, which is influenced by chemical and mechanical changes associated with exercise.

Normal breathing movements are controlled by involuntary, automatic, rhythmic discharges of nerve impulses from the **medulla** of the brain known as the **respiratory control centres**.

The **inspiratory control centre** sends motor nerve impulses to the external intercostal muscles of the ribs, and the muscles of the diaphragm, causing them to contract, and inspiration to occur. This active phase of the inspiratory control centre lasts for about two seconds. After this it automatically stops sending motor impulses for about three seconds, during which time the muscles of inspiration relax and expiration follows passively.

The basic rhythm of nervous control by the respiratory control centres is influenced by sensory inputs so that breathing alters in response to the demands of the body during exercise.

During forced breathing, when the inspiratory control centre reaches the end of each of its periods of rhythmic discharge, it sends nerve impulses to activate the **expiratory control centre**. Motor impulses from here stimulate the internal intercostal muscles and abdominal muscles to contract, resulting in forced expiration.

Ventilation of the lungs is a function of the rate and depth of breathing. Early on in exercise, ventilation is mainly increased by an increase in the depth of breathing, whilst later it is the rate of breathing that increases more.

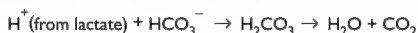
Any increase in the acidity of the blood (decrease in blood pH) and in the amount of carbon dioxide causes an increase in ventilation. A decrease in pH results mainly from an increase in the production of **lactate**, due to the increase in the rate of respiration associated with exercise. The level of acidity is monitored by **chemoreceptors** in the main aorta and in the carotid bodies in the arteries in the neck. Indeed, the sensitivity of the carotid bodies to a decrease in pH is thought to be a major factor controlling the increase in ventilation during exercise, along with nervous stimulation of the respiratory control centres from the contracting muscles and moving joints. Carbon dioxide stimulates the chemoreceptors in the carotid bodies and also exerts a direct effect on the respiratory control centres.

The respiratory control centres have connections with the cerebral cortex (conscious centres), so that a degree of voluntary control can be exerted over breathing movements. This is necessary for speech, and to exclude water from the lungs, as might be necessary in swimming. However, once the pH decreases below, and the carbon dioxide in the blood rises above, a certain level, the inspiratory control centre is stimulated, and voluntary control is overridden. It is these factors rather than shortage of oxygen that limit breath holding activities.

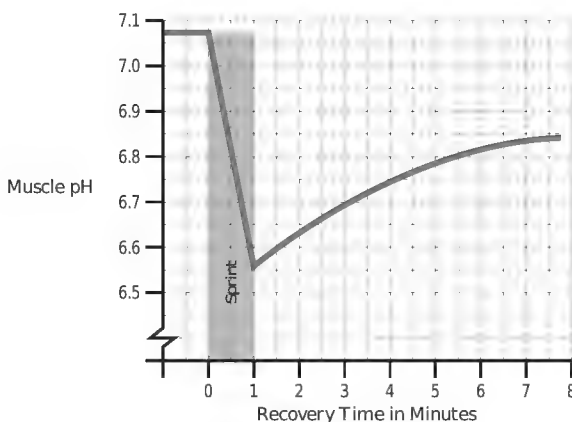
◆ CHECKPOINT SUMMARY

- ◆ The thorax is defined by the rib cage and its associated intercostal muscles, and the diaphragm.
- ◆ A system of air tubes; the trachea, bronchi and bronchioles form the 'bronchial tree' supplying the air sacs (alveoli) of the lungs
- ◆ Inspiration occurs when the intercostal muscles contract raising the rib cage, and the diaphragm contracts and flattens, increasing the volume and decreasing the pressure within the thorax below that of the external air pressure, resulting in the entry of air.
- ◆ Expiration at rest is passive, as the intercostal muscles and the diaphragm relax and the tissues of the thorax recoil as a result of their elasticity.
- ◆ The pleural fluid between the two pleural membranes lubricate the movement, and keep the lungs inflated against the wall of the thorax. Surfactants secreted inside the alveoli lower their surface tension and decrease their risk of collapse.
- ◆ The volume of air that is breathed during a complete breathing cycle of one breath in and one out is known as the tidal volume. Breathing becomes deeper as well as more rapid with exercise, and expiration becomes active.
- ◆ The vital capacity is the total amount of air that can be breathed with the deepest possible breath in and the deepest possible breath out.
- ◆ Breathing volumes can be measured with a simple spirometer. The principle involves a floating air (or oxygen) filled chamber which rises when the subject is breathing out and falls when the subject is breathing in. If the recording pen is attached directly to the chamber the recorded trace shows the movement of the chamber; if it is attached via a system of pulleys then the trace can be inverted.

The blood has a certain buffering capacity, that is under normal conditions it can resist changes in its pH restricting the changes in blood pH to between 7.2 and 7.45. As the lactate accumulates in the blood, it is buffered (initially at least) by combination with the hydrogen carbonate ions present in the plasma, increasing the amount of carbon dioxide in the blood.



An increase in the level of CO_2 in the blood stimulates the chemoreceptors in the carotid bodies, but its main effect is by direct stimulation of the respiratory control centres in the brain, resulting in an increase in the ventilation rate, and therefore more CO_2 being exhaled by the lungs.



Stretch receptors in the bronchi and the bronchioles are stimulated by the expansion of the lungs. Nerve impulses pass from these along sensory nerves to the inspiratory control centre, causing the reflex inhibition of the inspiratory motor nerve impulses. Therefore the muscles of inspiration relax, and expiration follows passively. However, this mechanism is not thought to be part of the normal control of breathing, but operates to protect the lungs from over-inflation. Other sensory receptors (proprioceptors) in the skeleton and muscles, also feedback sensory information to increase breathing movements during exercise.

The changes in blood levels of carbon dioxide, pH, and oxygen, together with mechanical feedback, cannot fully account for the large and rapid changes in ventilation experienced during exercise. Other factors increasing ventilation, include a rise in body temperature, and an increase in the blood levels of adrenaline and/or noradrenaline. The emotions are also involved, possibly via the sympathetic nervous system and the adrenal glands. The involvement of these may help explain the anticipatory rise in ventilation that can occur before the start of exercise.

◆ CHECKPOINT SUMMARY

- ◆ Breathing is controlled by the respiratory centre in the brain which receives stimuli from chemoreceptors in the blood vessels detecting the level of carbon dioxide, oxygen and pH in the blood, and stretch receptors in the lungs.
- ◆ Physical activity increases the demand for energy and thus the demand for oxygen.
- ◆ The increase in acidity (decrease in pH) stimulates the respiratory control centre to increase the rate and depth of breathing.
- ◆ If the demand for oxygen cannot be met anaerobic respiration occurs generating lactate (lactic acid).
- ◆ When sufficient oxygen is available it is used up in the oxidation of glucose with the production of carbon dioxide, which also stimulates the respiratory control centre to increase the rate and depth of breathing.
- ◆ The increased rate and volume of breathing maintains the diffusion gradients across the walls of the alveoli.

GAS EXCHANGE

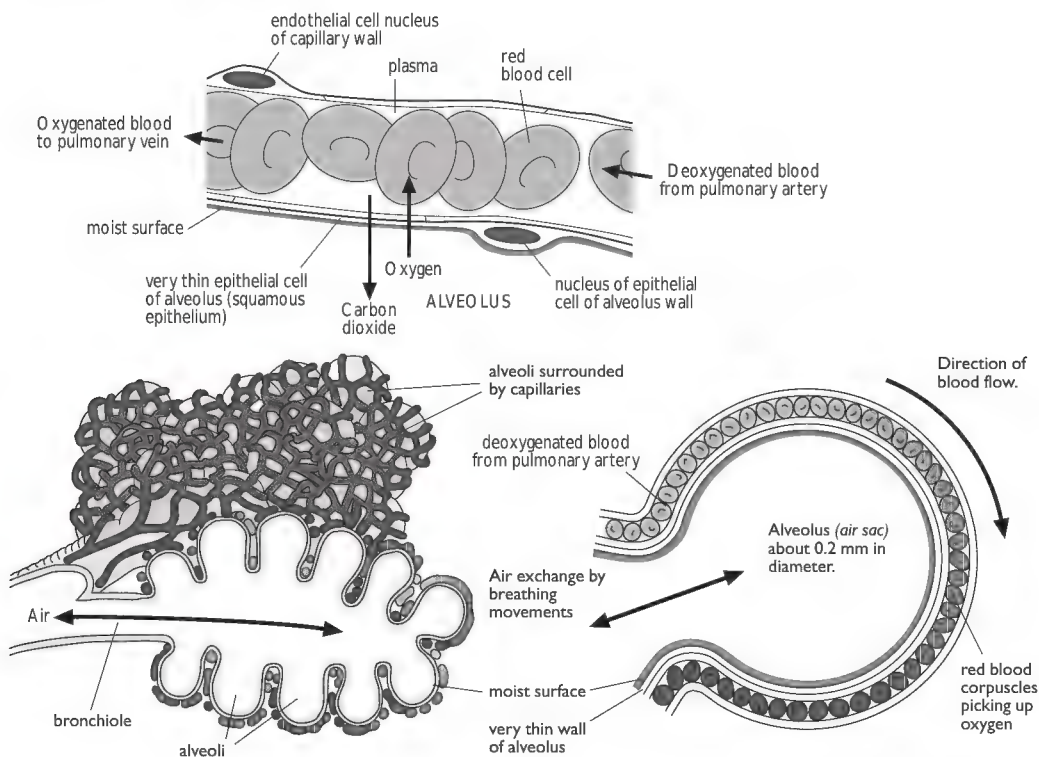
The structure and role of alveoli

Alveoli or air sacs make up the mass of the lungs. The bronchioles end in ducts which lead to the alveoli (small chambers used for gas exchange). Although each alveolus is very small, the large numbers of alveoli (around 700 million) provide an enormous surface area for gas exchange; in the region of 70-90m² in an adult human lung.

Each alveolus is surrounded by a net of capillaries which together form the **alveolar-capillary complex**. The endothelium of the capillaries is attached to the thin squamous epithelium of the alveolus via a shared basal membrane. The air inside the alveolus and the blood in the capillaries is thus separated by a distance of just the thickness of two layers of cells. This is one feature that helps rapid diffusion of oxygen from alveolus to blood and carbon dioxide from blood to alveolus. Other features include the large surface area already mentioned, and the steep diffusion gradients which are maintained between the blood and the alveolus due to the constant movement of the blood and the constant ventilation of the lungs.

The presence of a phospholipid material called **pulmonary surfactant** ensures that the tiny air sacs remain expanded even during expiration and do not collapse and stick together. Phospholipids act like a detergent, reducing the surface tension of fluids at the alveolar surface.

Gas exchange alveolus/capillary



The effects of smoking on ventilation and gas exchange

Tobacco smoke contains a mixture of many substances including irritant carbon particles, droplets of **tar**, the addictive chemical **nicotine** and a mixture of hot gases including the poisonous **carbon monoxide**. Of more than 1000 components identified at least 17 are known to be carcinogenic (cancer-causing). Many others are harmful in different ways, as demonstrated in studies on animals and observations in humans.

The effects of tar and other carcinogens in tobacco smoke on the gaseous exchange system are numerous. As discussed previously, efficient gaseous exchange relies on respiratory surfaces in the lungs having a large surface area, a short distance over which diffusion must occur, an effective ventilation mechanism and a good blood supply to deliver oxygen and remove carbon dioxide. It also relies on a network of airways to deliver air to these respiratory surfaces and mechanisms to limit the chance of dust or micro-organisms entering the lungs. Smoking can decrease the efficiency of all of these features in the following ways:

- ▼ Carbon monoxide binds to haemoglobin in red blood cells reducing the oxygen carrying capacity of the blood.
- ▼ Collection of tar on the alveolar surface increases the diffusion distance for gaseous exchange.
- ▼ Tar and other substances inactivate cilia and prevent them from clearing respiratory passages of dust and micro-organisms which can reach the alveoli leading to irritation and increased risk of infection.
- ▼ Inflammation of the bronchioles by tar and smoke causes constriction and secretion of fluid and mucus allowing less air into and out of the lungs (bronchitis) and breakdown of the alveolar walls forming larger chambers (emphysema) and a consequent reduction of surface area. Smoking may also make asthma worse.
- ▼ Nicotine may also cause constriction of bronchioles as a result of stimulating contraction of the smooth muscle in the walls of the 'bronchial tree'.
- ▼ Carcinogens in tar may lead to lung cancer which can eventually destroy large parts of the lung, preventing gas exchange.

All the effects mentioned above are linked to the number of cigarettes smoked, but there appears to be a significant genetic variation between individuals in the extent to which smoking affects lung function. Thus one individual may smoke only 5 cigarettes per day but develop severe emphysema by the age of 40 and lung cancer by 45, whilst another person may smoke 40 cigarettes per day and show no signs of associated ill health by the age of 90.

Even those exposed to the smoke of other people's cigarettes (**passive smoking**) are at an increased risk from a range of smoking related diseases. In families in which there is at least one heavy smoker, non-smoking individuals suffer 50% more respiratory illnesses than those coming from a non-smoking family. In addition, a large number of people have allergic reactions to tobacco smoke, which could be dangerous to those at risk from asthma, chronic bronchitis and coronary heart disease (CHD). A further sub-set at risk from passive smoking, are unborn babies who receive harmful substances across the placenta. Low birth weight, prematurity and increased risk of infant mortality are all associated with mothers smoking during pregnancy whilst perhaps as many as 1500 fetal deaths occur each year in the UK as a result of smoking.

Chronic bronchitis and emphysema

These two conditions are closely linked and often considered together, even though they each have distinct symptoms and signs. Together they are referred to as chronic obstructive airways disease (COAD) or chronic obstructive pulmonary disease (COPD). Between them they affect 17% of British men and 8% of women in the 40-64 age group, and, worldwide, cause well over 2 million deaths per year. Both conditions are almost entirely due to cigarette smoking. Sufferers may become so disabled that they are breathless even at rest and require oxygen cylinders at home.

Lung cancer

This is also known as **bronchial carcinoma** since it primarily affects the epithelial cells of the bronchioles. It is one of the most common causes of death in Britain and across the developed world. In excess of 35 000 people die from lung cancer each year in Britain, with a male: female ratio of 3.5:1. Over 90 % of these people are regular smokers. Non-smokers who contract lung cancer are often people who have been exposed to carcinogenic substances such as asbestos, coal products and oil based products through their work.

A few cells may break off the main tumour and be carried via blood or lymphatics to a distant site to form a secondary cancer (**metastasis**). Common sites for lung cancer metastases are in bones, the liver and the brain. It is often these metastases which eventually kill the patient.

Carbon monoxide

Motor vehicles produce up to 80 per cent of all man-made emissions of carbon monoxide in the world. It is a fairly persistent pollutant, lasting for several months in the atmosphere before being converted to carbon dioxide. Its main effect is that it combines irreversibly with haemoglobin in the red blood corpuscles to form stable carboxyhaemoglobin, thus preventing the carriage of oxygen to the tissues as oxyhaemoglobin. Carbon monoxide blood levels of up to 5 per cent are found in those breathing in heavy traffic fumes, and of up to 16 per cent in heavy smokers. However, atmospheric oxidation of methane (CH₄), produced by anaerobic decomposition of organic matter by decomposers is the major source of carbon monoxide in the air, with combustion of fuels by man accounting for only about 10 per cent of the total, (almost all in the northern hemisphere).

◆ CHECKPOINT SUMMARY

- ◆ Gas exchange occurs over large surface area of alveoli which is a product of their relatively small size and large number.
- ◆ Diffusion gradients of oxygen and carbon dioxide dependent upon partial pressures of gases on either side of diffusion surface.
- ◆ Diffusion surface composed of thin squamous epithelium ridged around the sandwiched capillaries, which further increases their surface area.
- ◆ Surface water an inevitable consequence of a permeable surface exposed to air decreases diffusion of oxygen more than the diffusion of carbon dioxide.
- ◆ Air in alveoli remains fairly constant in composition independent of breathing cycle.
- ◆ Diffusion gradients maintained by circulating blood.
- ◆ Smoking affects ventilation and gas exchange.
- ◆ As demand for oxygen increases so does steepness of diffusion gradients and speed of circulation thus meeting extra demand.
- ◆ The irritant components of tobacco smoke stimulate the production of excess mucus and inhibit the action of the cilia, leading to blockage of the smaller bronchioles and decreasing ventilation.
- ◆ Mucus and tar can accumulate in the alveoli reducing the surface area and increasing the diffusion distance for gaseous exchange.
- ◆ Harmful substances are absorbed into the blood and can affect the fetus across the placenta.
- ◆ Carbon monoxide is a component of tobacco smoke and car exhaust. It combines irreversibly with haemoglobin to form carboxyhaemoglobin, thus blocking the transport of oxygen.

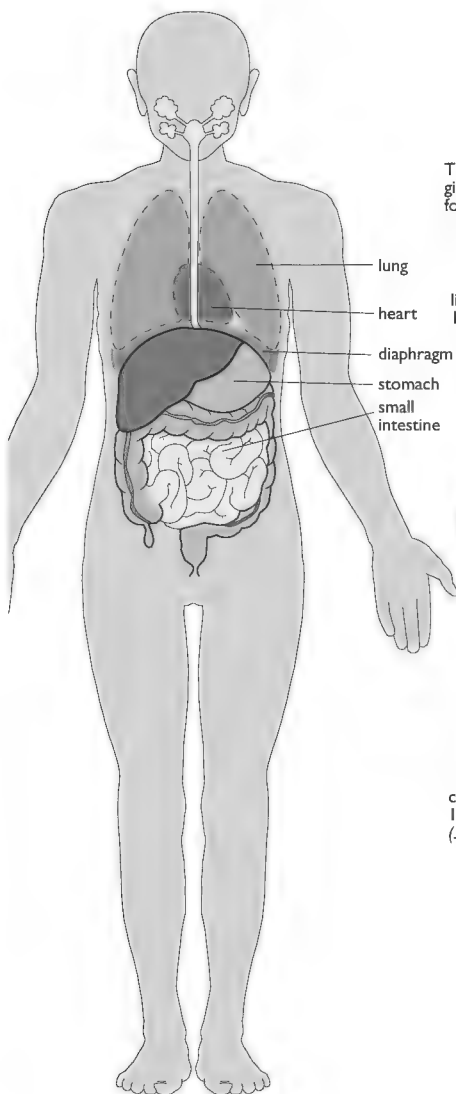
DIGESTION AND ABSORPTION

The structure of the alimentary canal

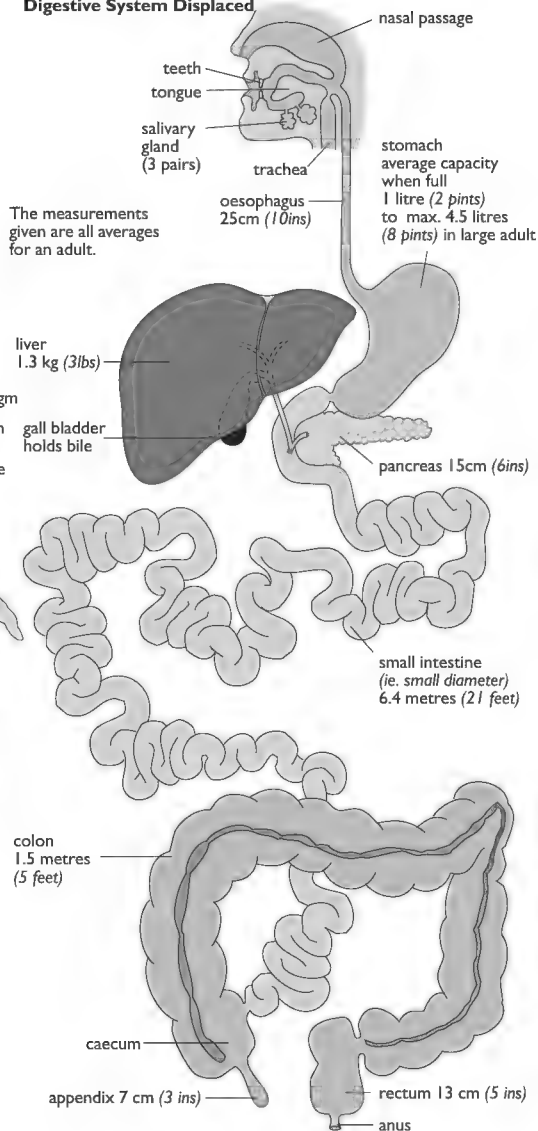
In humans, as in all other mammals, food is processed within a highly specialised alimentary canal or gut. Here the processes of digestion and absorption occur.

Digestion is the process whereby large complex organic molecules are broken down into smaller, soluble molecules.

Digestive System in Place



Digestive System Displaced



Absorption is the process whereby the simple, soluble products of digestion, along with water and inorganic mineral ions move through the wall of the gut and enter the blood and lymphatic systems for distribution around the body.

The alimentary canal forms a long, continuous tube from mouth to anus but it is divided into distinct regions with differences in appearance and function. The striking features of most regions are the modifications, at both gross and microscopic level, to create a very large surface area for digestion and absorption to occur.

Mastication of food

Food is ingested via the mouth where both **physical** and **chemical digestion** (by enzymes) begins. Within the mouth the food is moved between a range of specialised teeth by the muscular tongue and the cheeks. Molar teeth are adapted to grind the food, incisors to cut the food and canines to piece and tear the food. As food is chewed it is mixed with saliva from the salivary glands which contains the enzyme salivary amylase. This physical processing in the mouth has several important functions: it breaks the food into smaller pieces to make swallowing easier; it mixes the food with saliva to lubricate the food and aid swallowing; it increases the surface area of the food for the action of enzymes and it brings the food into contact with salivary amylase, the first of the carbohydrase enzymes. This begins the digestion of starch to maltose.

Movement of food along the gut.

Food is not moved through the gut by the forces of gravity, it is possible to swallow food and maintain normal movement of food through the gut whilst standing on your head! Instead the movement relies on smooth muscle in the muscularis externa (see below) of the gut wall. The muscles are controlled by the nerves of the autonomic nervous system (the branch of the nervous system which controls the basic processes of the body) which run through them. Along with hormonal signals these regulate the speed of movement of food through the gut and also allow the gut to move the food around as it goes.

The movement of food along the gut from the oesophagus towards the anus is known as **peristalsis**. Moving the food around within a region of the gut to allow it to be mixed with enzymes and other secretions hence aiding digestion and absorption is known as **segmentation**.

Peristalsis relies on two layers of muscle within the gut wall: the inner circular muscles and the outer longitudinal muscles contracting against the food material in the gut lumen. Although the process is really continuous, an individual wave can be considered in two stages. Firstly contraction of the longitudinal muscle and relaxation of the circular muscle leads to a widening of the lumen and shortening of the section of gut. Secondly relaxation of the longitudinal muscles and contraction of the circular muscles behind a bolus of food leads to a an elongation of the gut section and a constriction of the gut lumen. Between them these movements have the effect of squeezing the gut contents together and then pushing them along the gut. (A similar effect is achieved in trying to move toothpaste up a tube. First you compress an area of the tube and then you move the paste up the tube by moving your fingers along its length.)

When food is present, 10-12 such waves occur in the duodenum each minute with a smaller number (3-4) in the colon.

The histology of the ileum (small intestine) wall

The ileum, the longest part of the small intestine, is where the majority of digestion and absorption of food (proteins, fats and carbohydrates) takes place. In view of this the wall layers of this region of the gut are highly specialised for these functions.

In the ileum, as in all parts of the alimentary canal, the wall of the gut is composed of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa.

The **mucosa** lines the gut lumen and consists of epithelial cells overlying connective tissue and a thin layer of muscle. The epithelial cells have a range of secretory and absorptive functions in different gut regions. In all regions the mucosa contains numerous lymphocytes (white cells) to help protect from harmful foreign substances.

The **submucosa** consists of layer of dense connective tissue containing large blood vessels, lymphatic vessels and nerve fibres. The role of the capillaries and lymphatics is to absorb the products of digestion and transport them away from the gut.

The **muscularis externa** consists in most regions of an outer longitudinal muscle layer and an inner circular muscle layer. Together these aid movement of food within and through the gut by peristalsis. Nerves fibres run through the muscle layers to control the movements of the muscles.

The **serosa** is an outer layer of squamous epithelial cells forming a membrane

The submucosa and mucosa layers of the ileum form folds which increase the surface area for the absorption of food and slow the movement of food through this region. The mucosa forms finger like villi (0.5-1mm in height) which greatly increase the surface area for absorption.

Each villus contains blood capillaries to absorb small molecules such as glucose, and a lymphatic capillary (the lacteal) to absorb fats. A thin muscle layer helps each villus to move and hence come into contact with digested food molecules.

The cells of the villus are also specialised. Most bear surface projections called microvilli further increasing the surface area for absorption. Some of these microvilli have digestive enzymes attached to the cell membrane. Goblet cells on the villi secrete mucus to aid lubrication of food.

Cells found in the crypts of Lieberkuhn between the villi secrete a fluid containing mucus, salts and antibacterial substances. Some enzymes are released by the breakdown of cells at the tips of the villi.

Mucus and an alkaline fluid to neutralise the acid chyme of the stomach are secreted in the duodenum by the Brunner's glands located in the sub mucosa.

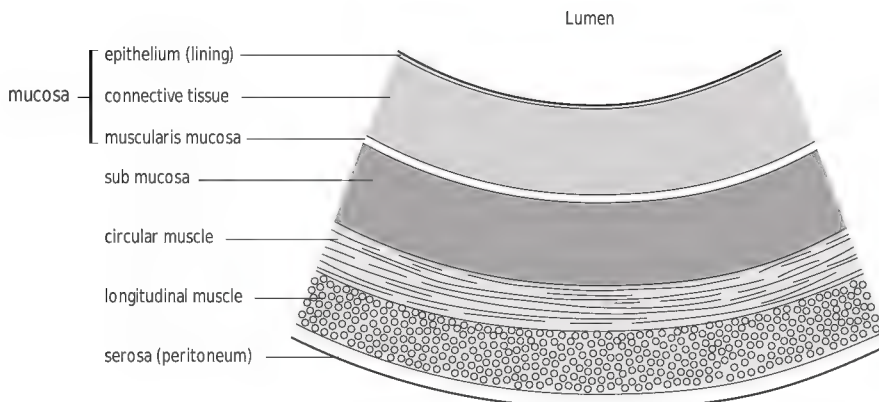
The muscularis externa in this region is responsible for peristalsis and segmentation as in other gut regions.

◆ CHECKPOINT SUMMARY

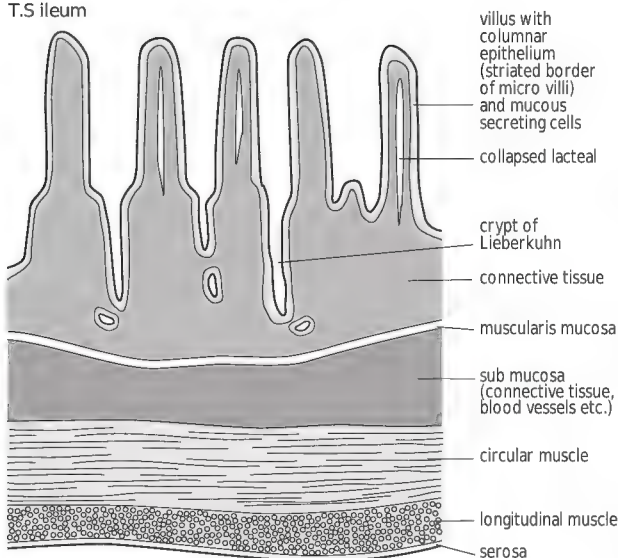
- ◆ Food is masticated by the teeth and the tongue to increase the surface area for digestion and to mix it with saliva for ease of swallowing.
- ◆ The smooth muscle moves the food through the gut by autonomic waves of contractions (peristalsis).
- ◆ The main regions of the gut are, the mouth (buccal cavity), oesophagus, stomach, duodenum, ileum, colon, and rectum.
- ◆ From the oesophagus to the rectum the wall of the gut is comprised of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa. These layers are modified in each region in accordance with its function.
- ◆ The oesophagus is lined with stratified epithelium. This is several layers of cells thick and protects underlying structures from damage. Mucous glands secrete mucus to lubricate the food, and thick layer of smooth muscle pushes food down by peristalsis.
- ◆ The stomach wall is folded and contains gastric glands which open into gastric pits. There are three types of secretory cells in these glands: mucus secreting cells, oxyntic cells secreting hydrochloric acid and chief cells secreting pepsinogen (later converted to the pepsin). Smooth muscle mixes and moves food into the small intestine

Unit 2H: Exchange, Transport and Reproduction in Humans

General plan of tissues of alimentary canal



T.S ileum



◆ CHECKPOINT SUMMARY

- ◆ The small intestine submucosa and mucosa form folds and villi which increase the surface area for the absorption of food and slow the movement of food.
- ◆ Goblet cells secrete mucus whilst Paneth cells found in the crypts of Lieberkuhn between the villi secrete antibacterial lysosome.
- ◆ Each villus contains blood capillaries to absorb all nutrients, and a lymphatic capillary (the lacteal) to absorb fats. The cells of the villus bear surface projections called microvilli.
- ◆ Brunners glands are restricted to the duodenum and secrete mucus and an alkaline fluid to neutralise the acid chyme.
- ◆ The large intestine consists of the colon where most water is absorbed, the caecum and appendix which are much reduced (vestigial) in humans, and the rectum into which faeces move before defaecation.

The digestion and absorption of carbohydrates.

Up to 70% of the human diet may consist of carbohydrates. A small proportion of these are taken as simple sugars (e.g. fructose in fruit) which do not require digestion, but the majority is in the form of starch, a large complex polysaccharide requiring digestion by enzymes. (Non-starch polysaccharides, mainly celluloses, are also eaten but provide no nutrients for humans since they cannot be digested.)

Carbohydrate digestion begins in the mouth where the enzyme salivary amylase begins to hydrolyse the 1-4 α -glycosidic bonds and digests starch to maltose (a disaccharide). When food reaches the stomach the action of this enzyme is eventually inhibited by the acid conditions.

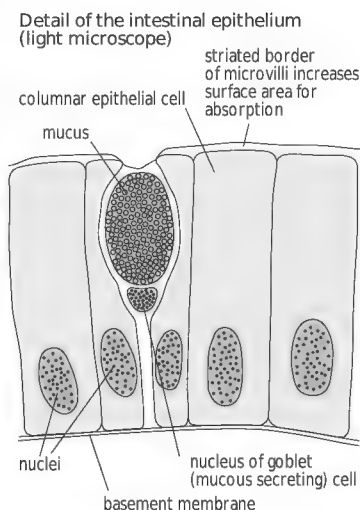
The bulk of carbohydrate digestion occurs in the small intestine. Pancreatic amylase, produced by the pancreas and secreted into the duodenum continues the digestion of starch to maltose. The alkaline salts in the pancreatic juice provide the optimum pH (8.5) for the pancreatic amylase to function. The release of pancreatic juice and pancreatic enzymes is stimulated by the hormones cholecystokinin (CCK) and secretin which are released in response to the presence of food in the gut.

Maltose is digested to glucose by the enzyme maltase which is embedded in the membrane of the microvilli of the mucosa. The glucose is then taken into the epithelial cells of the mucosa by active transport and passed into the bloodstream by facilitated diffusion.

In addition to maltase other disaccharidases are found on the surface of the microvilli. Here sucrase breaks down sucrose to form glucose and fructose, and lactase breaks down lactose to form glucose and galactose. Of these monosaccharides glucose and galactose are taken up into the cells by active transport whilst fructose moves in by facilitated diffusion.

All monosaccharides pass through the single layer of epithelium and into the blood capillaries to be transported to the liver.

The table below shows the sites of production, sites of action and function of some of the main groups of enzymes involved in carbohydrate digestion.



Name of enzyme	Site of production	Site of action	Function
Salivary Amylase	Salivary glands of mouth	Mouth	Digest starch to maltose
Pancreatic amylase	Pancreas	Lumen of small intestine	Digest starch to maltose
Sucrase	Epithelial cells of ileum	Ileum	Digest sucrose to glucose and fructose
Lactase	Epithelial cells of ileum	Ileum	Digest lactose to glucose and galactose
Maltase	Epithelial cells of ileum	Ileum	Digest maltose to glucose

2H.2

Transport of Materials

Contents

Circulation

- ▼ The functions of the circulatory system for the transport of respiratory gases, metabolites, metabolic wastes and hormones.

The circulatory system

- ▼ The structure of the human heart and coronary circulation.
- ▼ The cardiac cycle; myogenic stimulation; the coordination of the cardiac cycle.
- ▼ The normal ECG and the role of artificial pacemakers.
- ▼ The structure and roles of arteries, veins and capillaries.

Blood and body fluids

- ▼ The composition of blood as plasma and blood cells, including erythrocytes and leucocytes (neutrophils, eosinophils, monocytes and lymphocytes).
- ▼ The structure of erythrocytes and their role in transport.
- ▼ The roles of leucocytes in phagocytosis and secretion of antibodies.
- ▼ The transport of oxygen and carbon dioxide.
- ▼ The roles of respiratory pigments (haemoglobin, fetal haemoglobin and myoglobin).
- ▼ Dissociation curves of haemoglobin and the Bohr effect.
- ▼ The interchange of materials between capillaries and tissue fluid, including the formation and reabsorption of tissue fluid and the formation of lymph.

THE CIRCULATORY SYSTEM

The need for a circulatory system

The living cells of the human body are surrounded by a fluid medium called **tissue fluid** or extracellular fluid, with which they exchange materials. They obtain oxygen and nutrients from the tissue fluid and they excrete waste substances into it. Tissue fluid is referred to as the '**internal environment**' and specialised gas exchange and breathing systems exist for exchange to occur between this internal environment and the external environment.

Essential to this process is an efficient circulatory system. In the circulatory system, the blood flows entirely within a virtually closed system of vessels from the heart in the arteries, arterioles, capillaries, venules and veins back to the heart (although there are invariably some small blood spaces where the blood leaves the vessels e.g. in the liver).

The blood transports respiratory gases, metabolites (nutrients and materials synthesised within the body), metabolic wastes (e.g. urea). It also acts as a chemical messenger service, carrying hormones from the glands where they are produced to the target organs upon which they act.

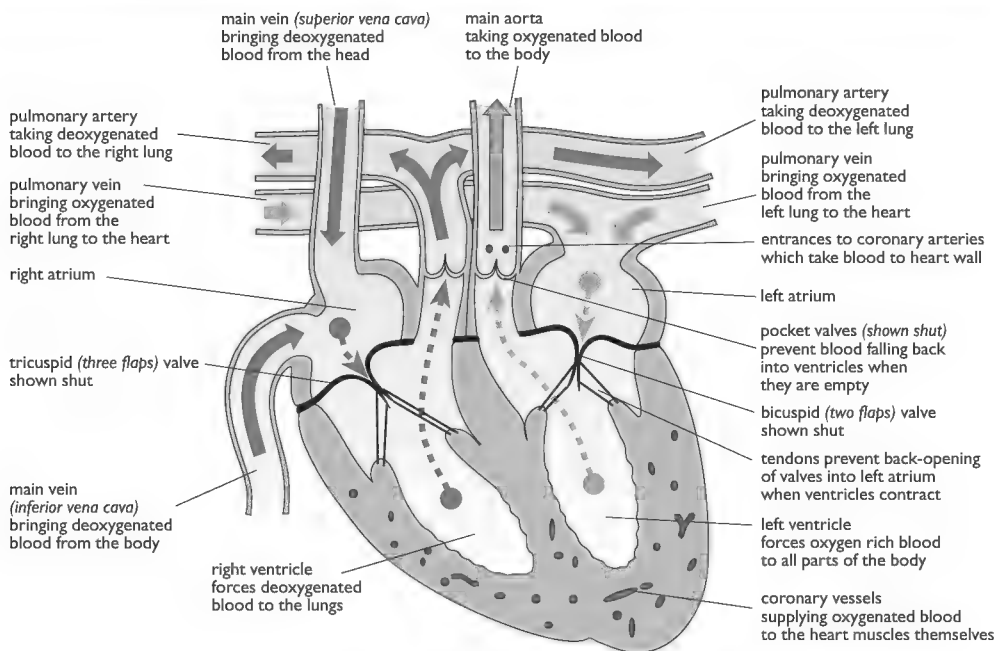
The structure of the mammalian heart

The heart is situated slightly to the left of the midline of the chest, protected by the ribs and by a tough membrane (pericardial membrane) which surrounds it in a fluid filled pericardial cavity. It is composed of four muscular chambers, two upper thinner walled atria, and two lower thicker walled ventricles. The right and left sides are divided from each other by a muscular septum. The right atrium receives blood in the vena cavae from the body, and the left atrium receives blood in the pulmonary veins from the lungs. (Note that diagrams of internal organs are always viewed from the front of the body, so that the right atrium and right ventricle appear on the left side of the diagram.)

The atria are separated from the main pumping chambers, the right and left ventricles, by flaps of fibrous tissue which act as one way valves. These atrio-ventricular valves differ from each other. The **tricuspid** valve on the right has three flaps, and the **bicuspid** valve on the left has two. These are attached to tendons and muscles which prevent them opening upwards under pressure.

◆ CHECKPOINT SUMMARY

- ◆ External appearance of heart shows small 'flap-like' atria, coronary blood vessels, fat deposits, and major vessels entering and leaving (venae cavae, pulmonary arch, and aortic arch).
- ◆ Coronary arteries arise just above the pocket valves at the base of the pulmonary and aortic arches, and supply the cardiac muscle of the heart wall with its own blood supply. Coronary veins return the blood to the right atrium.
- ◆ Internal structure of two atria and two ventricles.
- ◆ Chordae tendinae and muscles prevent back-opening of bicuspid and tricuspid valves when ventricles contract (ventricular systole).
- ◆ Pocket valves at base of pulmonary artery and main aorta prevent backflow of blood into ventricles when they relax (ventricular diastole).
- ◆ Atria walls thinner than ventricle walls.
- ◆ Left ventricle wall thicker than right ventricle wall to pump blood around body (systemic circulation).
- ◆ Right ventricle wall thinner than left ventricle wall as only has to pump blood via pulmonary circulation around lungs, where reduced pressure prevents formation of tissue fluid in alveoli.
- ◆ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.



Inside the entrance of the main arteries which leave the heart, the aorta and pulmonary artery, are two more sets of valves called semi-lunar or pocket valves, which when filled with blood block the arteries. Immediately above the semi-lunar valve in the aorta is the entrance to the **coronary artery** which supplies the heart muscle with nutrients and oxygen. The artery spreads its branches all over the surface of the heart. Deoxygenated blood is collected into the coronary vein which empties directly into the right atrium. The heart requires its own blood supply despite being filled with blood, as the blood that it is pumping is passing through too quickly, and the heart walls are too thick for diffusion to supply the needs of the heart muscle fibres.

The walls of the atria are less muscular than those of the ventricles, and the wall of the left ventricle is more muscular than that of the right ventricle. These differences reflect the different pressures that need to be generated in the chambers. The atria only have to pump blood into the ventricles. The right ventricle pumps blood to the lungs at a relatively low pressure. The lungs are close to the heart, and too high a pressure could damage the delicate alveoli and result in the filling of the lungs with fluid. The left ventricle must generate a high pressure to pump blood right around the body.

However, it is important to remember that the volumes of the lumens (cavities) of the chambers on the right side of the heart are the same as those on the left side of the heart, otherwise the right side would not be able to supply the left side with sufficient blood.

The cardiac cycle

The sequence of events that occurs during the filling and emptying of the heart is known as the cardiac cycle. At a rate of 70 beats per minute (bpm) the complete cycle takes about 0.86 seconds. It is a continuous sequence of events that occurs simultaneously on the left and right sides, but for the purposes of explanation it is convenient to consider it as occurring in a series of stages.

There is a point in the cardiac cycle when all the heart valves are shut, which can be taken as the starting point of the cardiac cycle.

Blood returning under low pressure in the main veins (superior and inferior venae cavae) from the upper and lower body enters the right atrium, and at the same time blood returning from the lungs in the pulmonary veins enters the left atrium.

Both atria fill with blood, and the rising pressure of the blood in the atria pushes open the tricuspid and bicuspid valves, and both ventricles begin to fill.

As the heart fills with blood both atria contract (**atrial systole**) forcing even more blood into the ventricles. These are now stretched, and they both contract (**ventricular systole**) forcing the blood upwards.

This upsurge of blood forces the tricuspid and bicuspid valves shut. These valves are prevented from back-opening into the atria by tough tendons, which are held taut by contraction of the papillary muscles to which they are attached. The closing of these valves makes the first heart sound (described as 'lub').

The blood is thus forced along the pulmonary artery to the lungs, and along the main aorta to the rest of the body, pushing open both sets of pocket or semi-lunar valves on the way.

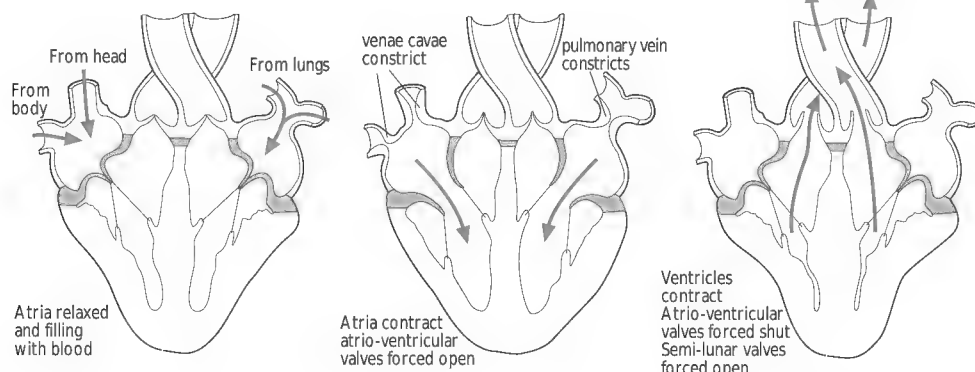
When the ventricles relax (**ventricular diastole**) the blood tends to fall back down the pulmonary artery and main aorta under gravity, thus filling and shutting the pocket valves. The closing of these valves makes the second heart sound (described as 'dup'). All valves are now shut and the cycle is repeated.

The heart sounds can be heard with the use of a stethoscope.

CHECKPOINT SUMMARY

- ◆ The cardiac cycle refers to the events of a complete filling and emptying of the heart.
- ◆ It is a continuous cycle, the start point of which can be taken when heart is empty and all valves shut.
- ◆ Atria fill and internal pressure rises forcing bicuspid and tricuspid valves open.
- ◆ Ventricles fill so that whole heart full.
- ◆ Atria contract (atrial systole) so that ventricles overfilled and stretched.
- ◆ Ventricles contract with a force proportional to their degree of stretch (ventricular systole).
- ◆ Blood forced up shutting bicuspid and tricuspid valves (first heart sound) and opening pocket valves as blood forced up pulmonary artery and aorta.
- ◆ Ventricles relax (ventricular diastole) blood falls back in pulmonary artery and aorta shutting pocket valves (second heart sound).

Cardiac Cycle



Initiation and control of heart action

Cardiac muscle is myogenic, that is the stimulus for contraction arises internally, rather than externally from branches of the nervous system as seen with skeletal muscle.

Sino-atrial node

The sino-atrial node (SA node) or 'pacemaker' is a mass of specialised tissue in the right atrium from which coordinating waves of electrical activity originate and radiate through the muscle of the heart wall. The sino-atrial node thus coordinates the basic rhythm of the heart contractions.

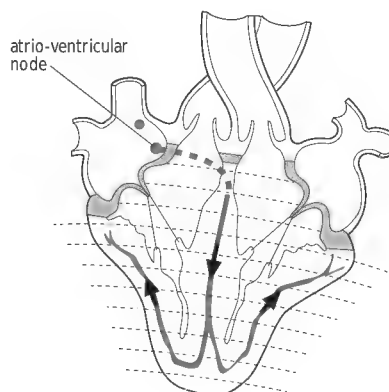
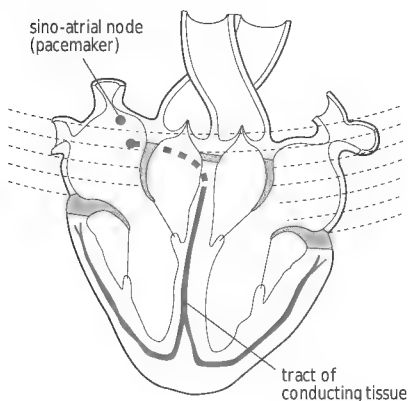
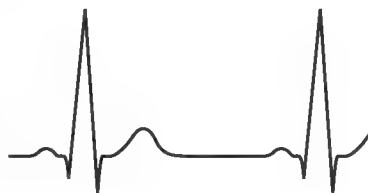
The wave of excitation spreads rapidly through the interconnected cardiac muscle fibres of the atria allowing both to contract simultaneously. A band of fibrous connective tissue between the atria and ventricles prevents the wave of excitation spreading down into the ventricles.

Atrio-ventricular node

Another mass of specialised tissue, the atrio-ventricular node is located at the bottom of the atria. It is stimulated by the waves of electrical impulses radiating from the SA node, and transmits the impulses through the insulating band of connective tissue between the atria and ventricles. The impulse travels to the base of the ventricles in a tract of conducting tissue, composed of modified cardiac muscle fibres and neurones known as Purkyne tissue, from where the impulses radiate upwards through the cardiac muscle of the ventricles.

This pattern of the spread of excitatory waves through the heart, ensures that the atria contract first to force the blood **down** into the ventricles, and that the ventricles subsequently contract to force the blood **up** into the pulmonary arteries and main aorta. The spread of the wave of excitation throughout the heart can be detected by electrodes attached to the skin of the chest and displayed as an electrocardiograph (ECG trace).

ECG trace of electrical activity of heart



The onset of strenuous activity can result in ECG abnormalities due to insufficient blood flow to the heart muscle in the first few seconds. This can be prevented by a two minute warm up period before exercise.

Although the sino-atrial node initiates contractions of the heart it cannot vary the rate of stimulation on its own. The basic rate of the sino-atrial node, can, however, be altered by a variety of influences, over a range from about 30 beats per minute (bpm) to as many as 220 bpm.

It is influenced by the activity of the sympathetic and parasympathetic nerves of the autonomic nervous system, which originate from a control centre in the brain.

The sympathetic nerves secrete noradrenaline, which stimulates an increase in the heart rate directly.

The parasympathetic nerves, release acetylcholine which causes a decrease in the heart rate. During exercise, the progressive increase in the heart rate is due at first to a decrease in parasympathetic activity, and then to the increasing activity of the sympathetic nervous system.

Also, in response to a general activation of the sympathetic nervous system, adrenaline is released into the blood stream from the adrenal glands, which also increases the heart rate.

Stimuli for these changes include the levels of blood carbon dioxide, pH, and temperature. Increases in these levels, associated with increased activity, result in an increase in the rate of contraction of the heart (beats per minute).

Artificial pacemakers

When the mechanisms controlling the cardiac cycle break down the rhythm of the heart may be induced artificially by means of a pacemaker. An artificial pacemaker is a small battery powered electrical stimulator implanted beneath the skin, electrodes from which are connected to the right ventricle. The pacemaker takes over control of the ventricles by generating rhythmic pulses of electricity causing muscular contraction. The device is located in an accessible position so that batteries can be periodically replaced (every five years or so).

◆ CHECKPOINT SUMMARY

- ◆ Rate modified by sino-atrial node (pacemaker) in wall of right atrium.
- ◆ Cardiac muscle is myogenic.
- ◆ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ◆ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ◆ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from where it radiates up through the walls back to the connective tissue barrier.
- ◆ Detected by electrodes on the skin as an ECG.
- ◆ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline.
- ◆ Pressure receptors in the main veins and arteries close to the heart detect pressure changes and regulate the cardiac output by reflexes via the medulla of the brain.
- ◆ All influences on heart coordinate heart rate and therefore blood supply to body with demands of body.

The structure and roles of arteries, veins and capillaries

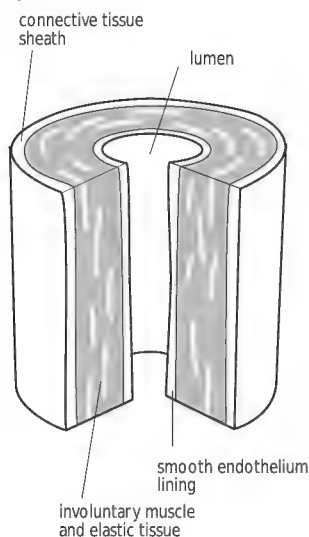
In mammals the blood circulates around the body in a continuous system of blood vessels. From the heart, blood travels in the arteries and arterioles, into the capillaries supplying the tissues, and then returns to the heart in the venules and veins.

Arteries

Arteries close to the heart have a large cross sectional area, and thick elastic walls to withstand the high blood pressure. Arteries are stretched by the cardiac output when the heart contracts, and they recoil when the arterial blood pressure drops as a result of the heart relaxing between beats. The recoil of the elastic artery walls in this way assists the circulation of the blood around the body. It helps smooth the flow between contractions of the heart, and helps to maintain the blood pressure. This stretching and recoiling of the arteries is felt as the pulse in places where arteries come close to the surface of the body (the inside of the wrist, the side of the neck, and in the temple).

The main artery leaving the left ventricle of the heart, the aorta, branches into arteries supplying all the main regions of the body. Further from the heart, there is a gradual transition from the elastic arteries to muscular arteries that have circular layers of involuntary muscle in their walls. These arteries branch into smaller **arterioles** the walls of which, although thinner, also have circular layers of involuntary muscle. The state of contraction or 'tone' of these muscle layers alters the diameter of these vessels, which changes the resistance to the flow of the blood, which in turn effects the blood pressure and distribution of the blood to different parts of the body. The arterioles penetrate all tissues of the body and connect to beds of finely branching capillaries.

Artery in section



Capillaries

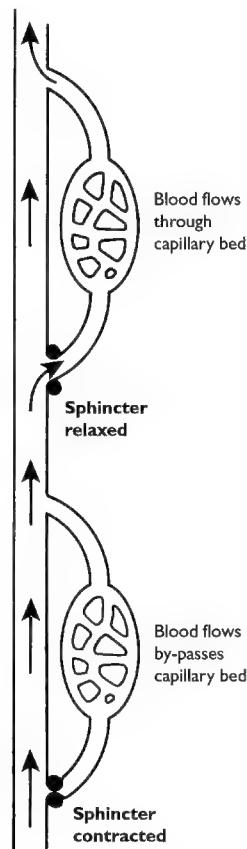
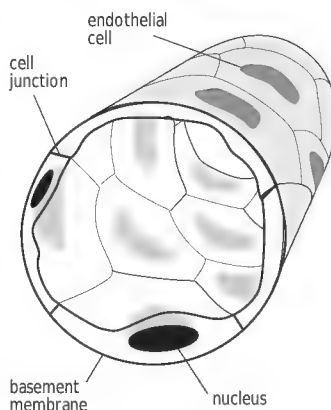
Capillaries form a fine network which penetrate all tissues. They have the smallest diameter of all blood vessels, about $6-8\text{ }\mu\text{m}$ (0.007 mm), which is the same as that of the red blood cells. For this reason the red cells are forced to move slowly through the capillaries in single file, ensuring a short diffusion distance between the corpuscles and the tissues. Capillary walls are just one cell thick, which further aids exchanges by diffusion between the blood and the tissues. The huge number of capillaries provide a very large total surface area across which these exchanges occur. As more capillaries open up in working muscles, the surface area between the blood and tissues is increased, and the diffusion distance between the two is decreased, resulting in more rapid and efficient exchanges between them. The blood pressure and rate of flow both drop in the capillaries. The slow flow also increases the time available for exchange of materials between the blood and the tissues.

There are so many capillaries in the body that they cannot all be supplied with blood at the same time. Consequently, there is competition for blood between different regions of the body, especially during exercise, when blood must be shunted to the working muscles, and consequently withdrawn from other regions. For example, when the body is at rest, about 45% of the cardiac output passes through the capillaries of the gut wall and associated glands, and the kidneys. During maximum exercise this can be reduced to about 3% of the cardiac output, as blood is redirected to the working muscles. The reduced flow rate is compensated for by a greater extraction of oxygen from the blood, by these tissues. The shunting of blood between competing tissues is achieved by constriction and dilation of the arterioles, and of the arterio-venous vessels, which are direct connections between the arterioles and venules. The entrances to the capillary beds are controlled by circular precapillary sphincter muscles which, when contracted, shut off the capillaries and when relaxed, open them.

Estimated blood flow in cm^3 per minute, to different organs/systems in a trained male at rest and during maximum effort.

Organ system	At rest	%	Max. effort	%
Skeletal muscle	1000	20	26 000	88.00
Coronary vessels	250	5	1200	4.00
Skin	500	10	750	2.50
Kidneys	1000	20	300	1.00
Liver & gut	1250	25	375	1.25
Brain	750	15	750	2.50
Whole body	5000	100	30 000	100.00

Section of typical capillary



Veins

Capillaries join up to form **venules**, which in turn join to form veins which return the blood to the heart. The individual veins have a larger cross sectional area than the comparable arteries, and as there are more veins than arteries, the veins also have a greater total cross sectional area. The walls of the veins are thinner and less elastic than those of the arteries, and in the veins of the legs and arms there are semi-lunar or pocket valves at intervals along their length. These valves oppose any back flow of blood under gravity, and ensure one-way flow of blood to the heart when the veins are 'massaged' by movement of surrounding tissues (especially contracting skeletal muscles). The thin walled veins with their large cross section present little resistance to the flow of the blood, so that although the blood pressure in the veins is low after passage of the blood through the capillary beds, the remaining pressure still helps move the blood in the veins back to the heart.

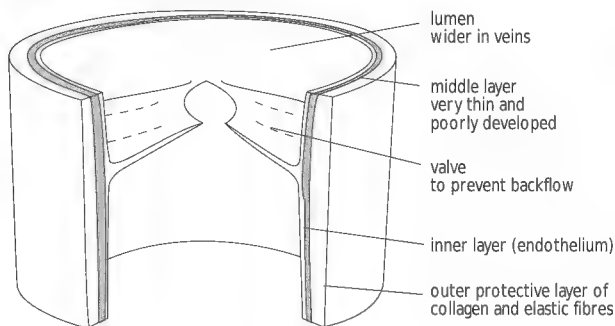
Because the blood in the veins is under low pressure, and their walls are thin, the veins are easily compressed by the smallest movements of the surrounding structures, particularly the skeletal muscles. As the muscles contract and relax during exercise they exert a massaging effect on the deep veins, especially for example in the legs, when running, swimming, or cycling. This massage effect of the 'muscle pump' is random and in no particular direction, but the pocket valves in these veins ensure that the flow is one-way, back to the heart.

In addition, breathing movements assist the return of blood in the veins to the heart. On breathing in, the diaphragm contracts and moves downwards. This decreases the pressure within the thorax, and increases the pressure within the abdomen. These changes in pressure compress the large veins in the abdomen, and assist the flow of blood into the veins of the thorax which return blood to the heart.

At rest the veins act as a large reservoir of blood for use when circulatory demands increase, for example during exercise. During exercise when the output of blood from the heart (cardiac output) increases, the muscle fibres in the walls of the veins are stimulated to contract (venous tone) and the veins constrict. As a result a larger proportion of the venous blood is shunted back to the heart, especially from the veins in the legs and the abdomen. This is especially important in preventing blood from 'pooling' in the legs under the force of gravity during upright exercise, and immediately afterwards.

In these ways the venous return of blood balances the rising cardiac output during exercise. This is essential as the heart would be unable to maintain a high cardiac output unless it was receiving an equal volume of blood back from the veins.

Section of vein showing pocket valve



◆ CHECKPOINT SUMMARY

- ◆ Elasticity of arteries is important in smoothing flow of cardiac output - the pulse.
- ◆ Finer branches and arterioles main site of generation of resistance to blood flow and generation of blood pressure.
- ◆ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ◆ Capillaries have large total cross sectional surface areas. Therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ◆ Diameter of capillary same as red blood corpuscles thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ◆ Plasma minus proteins exuded through thin walls to bathe tissues directly.
- ◆ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ◆ Pocket valves ensure one way flow back to heart.
- ◆ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

BLOOD AND BODY FLUIDS

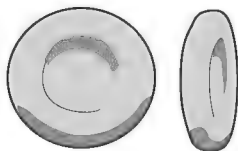
Composition of the Blood

Blood consists of the fluid plasma, which carries red blood cells, white cells, and fragments of cells from the red bone marrow known as platelets.

Plasma consists of 90% water, and 10% materials in suspension and solution. Plasma proteins, formed mainly in the liver, include albumin (to which the plasma calcium is bound), globulins (some of which are antibodies and others are important in the carriage of hormones and vitamins), and fibrinogen (which is important in blood clotting). These proteins also have an important function in buffering the blood (preventing sudden changes in acidity and alkalinity). Plasma proteins are also involved in regulating the movement of water between blood and tissues, they lower the water potential of the plasma which helps to control the volume of tissue fluid being formed and reabsorbed. Plasma also contains many dissolved organic and inorganic substances which are being transported, e.g. amino acids, hormones, glucose, fats, urea, creatine, bicarbonate, some oxygen and carbon dioxide. The characteristic yellow straw colour comes from a pigment called bilirubin which is formed from haemoglobin when old red blood cells are broken down in the liver.

Red blood cells (erythrocytes) lose their nucleus and most of their cytoplasmic organelles in their process of maturation in the red bone marrow. They become 'corpuscles' with a flexible membrane, filled with the oxygen carrying pigment haemoglobin. The loss of the nucleus accounts for their biconcave shape which increases their surface area to volume ratio. The total surface area of the red blood cells in man is about 3500 m^2 and this facilitates the exchange of gases between the red cells and the tissues. The biconcave shape also gives them some resilience in absorbing water without bursting should the plasma become temporarily diluted for any reason. The flexible membrane enables them to 'squeeze' through capillaries.

Red blood cells comprise about 30-40% of the blood volume. This can be determined by centrifuging a blood sample which results in the red blood cells being forced down to the bottom of the sample to give a 'packed red cell volume' or haematocrit. The haematocrit (and the red blood cell count) are proportional to the haemoglobin content of the blood which is quoted in grams per litre (decimetre cubed (dm^3), with normal values being within 140-180 for men, and 115-160 for women. (Clinically the figures are quoted in grams per decilitre (one tenth of a litre) and are given as 13 - 17g for adult males and 11.5 - 16.0g for adult females.) Levels below the lower limits being known as anaemia.



Red cell approx. $7 \mu\text{m}$ in diameter

White cells (leucocytes) form the basis of the immune system. They comprise just 1% of the total blood volume. There are four main types of leucocyte which differ in both structure and function. They are all found in the blood, although most actually function outside of the capillaries in the tissues.

Neutrophils are the most common type and make up approximately 70% of leucocytes. They are small phagocytic cells which engulf foreign particles e.g. invading disease causing micro-organisms (pathogens). They have a characteristic multi-lobed nucleus, surrounded by granular (grainy) cytoplasm.

Eosinophils possess a bi-lobed nucleus and granular cytoplasm, these leucocytes usually only comprise 1.5% of the total leucocyte population. However, in the blood of individuals suffering from allergic conditions, the proportion of eosinophils is increased as they play a role in allergic responses. They are also involved in the destruction of large parasites such as flatworms.

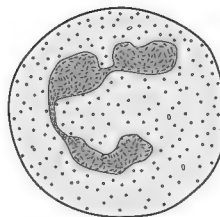
Monocytes can be identified by their large 'bean-shaped' nucleus and non-granular cytoplasm. They originate in the bone marrow, spend a short time in the blood, and then settle in tissues where they become known as **macrophages**. Monocytes secrete chemical known as cytokines which are essential for the functioning of the immune system. Macrophages are involved in the phagocytosis of micro-organisms and other large particles. Macrophages are also found in the alveoli of the lungs where they attack pathogens entering via the air.

Lymphocytes are involved in specific immune responses to pathogens or other foreign cells. They are round in shape with a large, densely staining nucleus. The small amount of cytoplasm is non-granular. There are two main types:

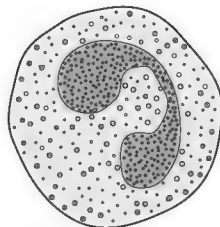
B-lymphocytes which produce antibodies and **T-lymphocytes** which are involved in the direct killing of infected cells.

Role of leucocytes in phagocytosis

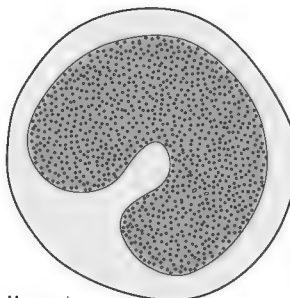
Phagocytosis is the process by which pathogens, other foreign material and dead or infected cells are engulfed and digested by neutrophils or monocytes/macrophages (collectively known as **phagocytes**). These phagocytes are non-specific in their actions so will deal with any type of foreign material which they come across. Phagocytes are found in the blood and the lymphatic system, especially in the lymph nodes as well as in the intercellular spaces of tissues.



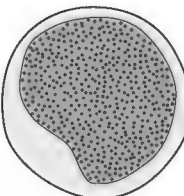
Neutrophil



Eosinophil



Monocyte

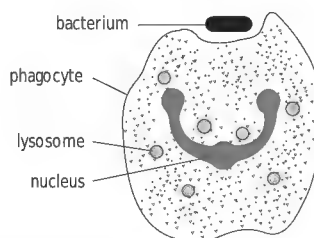


Lymphocyte

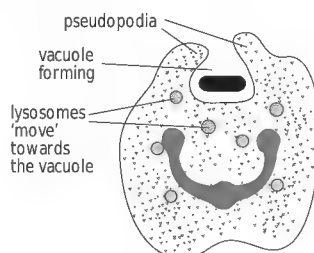
Unit 2H: Exchange, Transport and Reproduction in Humans

- ▼ Neutrophils appear in blood, lymph and tissue sites, and macrophages are found primarily in tissues. This is important as it allows them to act in any tissue which becomes infected with pathogens.
- ▼ The process of phagocytosis in both neutrophils and macrophages involves several stages.
- ▼ The phagocyte comes into direct contact with the foreign particle or microorganism.
- ▼ The cell membrane and cytoplasm of the phagocyte moves out forming 'pseudopodia' around the particle or micro-organism.
- ▼ The particle or micro-organism is enclosed in a vacuole (called a phagosome) formed from the cell membrane of the phagocyte.
- ▼ Lysosomes in the cytoplasm, containing enzymes and other chemicals, fuse with the phagosome and discharge their contents.
- ▼ The micro-organism or other cell material is killed and digested, and the products of digestion are absorbed by the phagocyte or released from the cell.

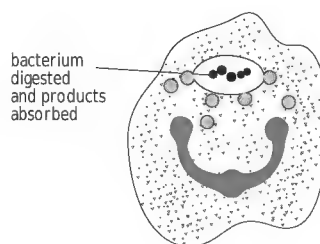
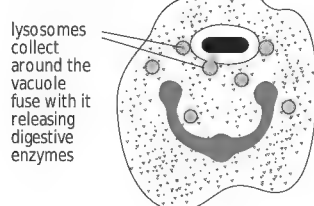
Phagocyte 'moves' towards bacterium



Vacuole forming



Vacuole formed



◆ CHECKPOINT SUMMARY

- ◆ Blood consists of fluid plasma with erythrocytes (red blood cells), and leucocytes (white blood cells) and blood platelets.
- ◆ Plasma composed of 10% materials in suspension and solution.
- ◆ Plasma proteins wide variety of functions and act to buffer changes in pH.
- ◆ Materials carried in solution not strictly part of the plasma.
- ◆ Red blood cells lose nucleus in development and become biconcave corpuscles of haemoglobin.
- ◆ Red blood cell volume 30-40% of total blood volume.
- ◆ Large surface area to volume ratio individually due to biconcave shape, and huge total surface area due to small size (6-8 mm) and huge numbers.
- ◆ Males higher blood count/haemoglobin than females.
- ◆ There are several types of leucocytes (neutrophils, eosinophils, monocytes and lymphocytes) and they form basis of immune system.
- ◆ Leucocytes engulf foreign particles e.g. bacteria and viruses by phagocytosis, and secrete antibodies against foreign antigens, including bacteria and viruses.
- ◆ Platelets are fragments of white cells.

Role of leucocytes in the secretion of antibodies

B-lymphocytes are involved in the specific immune response to pathogens (or other foreign antigens) via the production of antibodies.

On the cell surface membrane of B-lymphocytes are a number of specific antigen receptors or membrane bound antibodies. These are sites to which antigens on the surface of pathogens or other foreign material may become attached, leading to a sequence of events in which free antibodies are produced to destroy the foreign material.

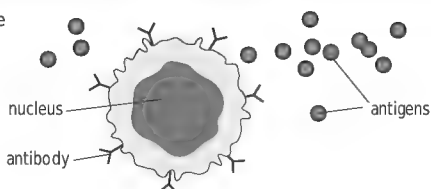
Antibodies are a type of protein molecule known as immunoglobulins which are secreted by activated B-lymphocytes when a specific antigen is encountered. Antibodies do not directly destroy foreign material but target it for destruction by other branches of the immune system, including phagocytes.

Sequence of events in the production of antibodies

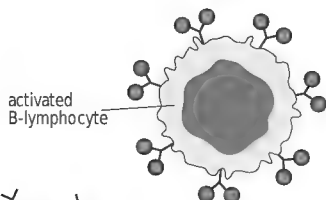
- ▼ Antigens on surface of foreign material come into contact with their specific antigen receptor on a B-lymphocyte. (Note there are thousands of types of B-lymphocyte each with different receptors and the ability to make just one type of antibody.)
- ▼ Binding of antigen to antigen receptor activates the B-lymphocyte and causes it to divide by mitosis producing a clone of identical B-lymphocytes.
- ▼ Most of the B-lymphocytes turn into **plasma cells** and the rest turn into **memory cells**.
- ▼ The plasma cells begin to secrete specific antibodies against the foreign material concerned. Antibody molecules are secreted at a very high rate (up to 30 000 molecules per second).
- ▼ The antibodies attach to the antigens on the foreign material and lead to the destruction of it in one of three ways.
- ▼ By coating foreign cells or objects and causing them to stick together in such a way that they can then be engulfed by phagocytes (another type of white blood cell).
- ▼ By binding to the foreign cells or objects at sites which interfere with their activities. For example, by covering the protein coat of a virus and preventing it from attaching to host cells.
- ▼ By stimulating the release of other blood components to break up and destroy foreign cells.
- ▼ Once the foreign material has been destroyed, the plasma cells eventually die and antibodies stop being secreted. But the memory cells remain in the lymph nodes and the circulation. If a subsequent infection with the same pathogen occurs then some of these will turn into plasma cells and start producing antibodies. This is the basis of **natural active immunity** to diseases and underlies the practice of immunisation or vaccination.

Platelets are white cell fragments, which have an important function in the clotting process.

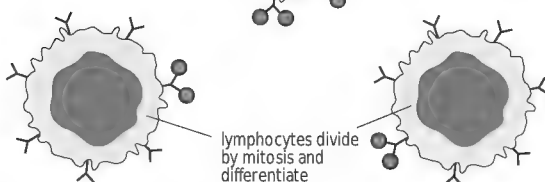
Immature B-lymphocyte



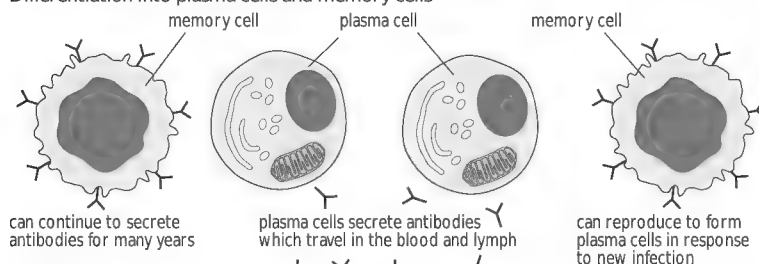
Activation



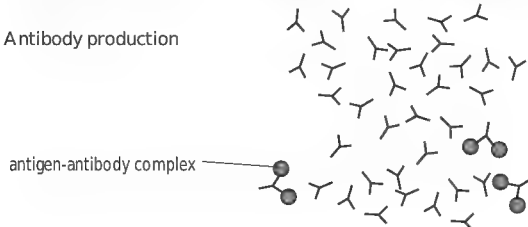
Division



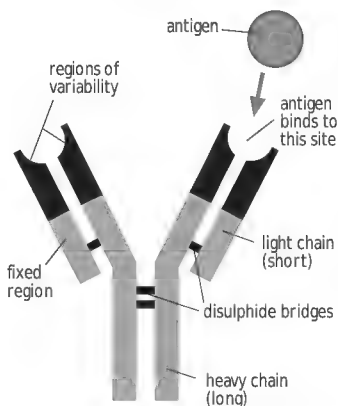
Differentiation into plasma cells and memory cells



Antibody production



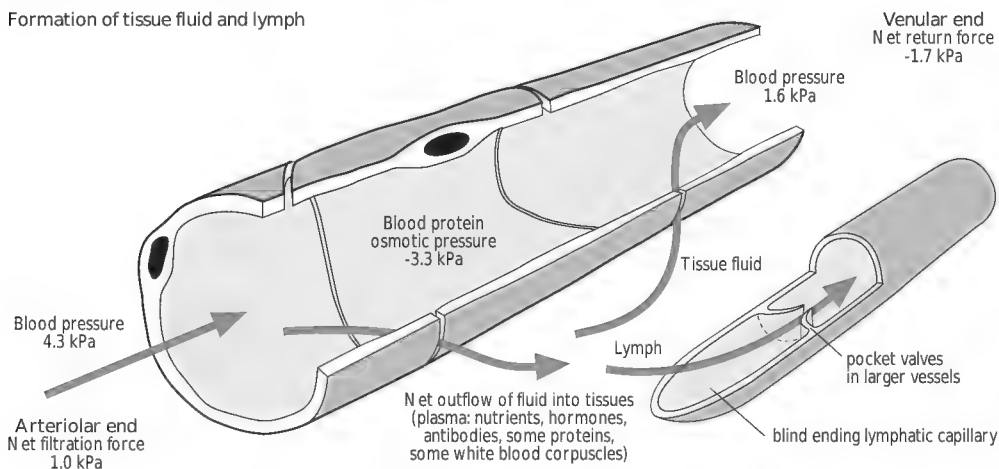
Structure of an antibody



Tissue fluid

Tissue fluid is formed when plasma, minus its proteins, is pushed out under pressure through the capillary walls to bathe the tissues. Depending on the degree of activity and health and fitness, most of the tissue fluid is reabsorbed back into the blood capillaries. Tissue fluid forms the internal environment of multicellular animals. It bathes each cell and is the medium for the exchange of materials between the individual cells and the blood system.

Formation of tissue fluid and lymph



◆ CHECKPOINT SUMMARY

- ◆ The hydrostatic pressure of the blood in the capillaries causes plasma minus its proteins to be forced through the thin walls of the capillaries.
- ◆ This fluid bathes all the tissues and is known as tissue fluid.
- ◆ It carries substances in solution from the blood to supply the tissues, e.g. oxygen, nutrients, hormones, antibodies etc; and drains waste products e.g. carbon dioxide away.
- ◆ Most of the tissue fluid is reabsorbed back into the capillaries as the hydrostatic pressure drops as the blood passes through the capillaries.
- ◆ Excess tissue fluid is drained away into blind ending lymphatic capillaries.
- ◆ Lymph is tissue fluid that has been drained into lymphatic capillaries, with lymphocytes added by lymph nodes which occur at intervals.
- ◆ Special lymph capillaries in the villi of the lining of the small intestine, known as lacteals, preferentially absorb and transport fats, so that lymph contains more fats than plasma.
- ◆ Eventually the lymph is returned to the general circulation in the major veins near to the heart.
- ◆ Movement of the lymph in the lymphatic system is maintained by the massaging effects of the muscles and breathing movements, and the one-way pocket valves; all features common to the veins of the circulatory system.

The transport of oxygen and carbon dioxide

Gas exchange occurs by diffusion between the air in the alveoli of the lungs and the blood in the capillaries. The relative amounts of oxygen and carbon dioxide in the air breathed in and out are measured as '**partial pressures**' in units of kiloPascals (kPa). (The continuous random movement of particles of a gas means that the particles will occasionally collide with each other and with the walls of any structure enclosing them within a space, thus exerting a pressure. The number of such collisions, and therefore the pressure, is proportional to the amount of substance present. In mixtures of gases, e.g. air, each substance exerts a partial pressure in that mixture proportional to the amount of that substance in the mixture. The partial pressure of a gas is a better measure of the amount of gas present than its percentage composition. Although the percentage of oxygen remains the same (21%) in air under different conditions, the amount of oxygen varies. At atmospheric pressures less than at sea level, e.g. at altitude, there is still 21% oxygen in air, but as the air is less dense there is a smaller amount of oxygen.)

As a result of its journey around the body, blood entering the capillaries of the alveoli has a lower oxygen and a higher carbon dioxide content (partial pressure) than the air in the alveoli. Therefore carbon dioxide diffuses out of the blood into the alveoli, and oxygen diffuses into the blood from the alveoli, each down their partial pressure gradients.

Roles of respiratory pigments (haemoglobin, fetal haemoglobin and myoglobin)

Oxygen absorbed into the blood in the alveolar capillaries combines with **haemoglobin** in the red blood cells to form **oxyhaemoglobin**. Each molecule of mammalian haemoglobin consists of four sub-units, each consisting of an iron-containing haem group combined with a protein globin part. Each subunit combines reversibly with one molecule of oxygen. Thus one molecule of haemoglobin can carry four molecules of oxygen. The formation of oxyhaemoglobin from deoxyhaemoglobin involves a physical holding of the oxygen by the haemoglobin sub-units as a result of their special 3-dimensional structure. In man each red blood cell contains about 300 000 000 molecules of haemoglobin. At rest and even during maximum exercise, at sea level, the haemoglobin in the blood leaving the lungs in healthy subjects is virtually saturated with oxygen. Therefore the capacity and functioning of the lungs is not normally the limiting factor in exercise. (The oxygen is easily displaced by carbon monoxide, which combines irreversibly with haemoglobin to form carboxyhaemoglobin. Major sources of carbon monoxide being smoking and car exhausts.)

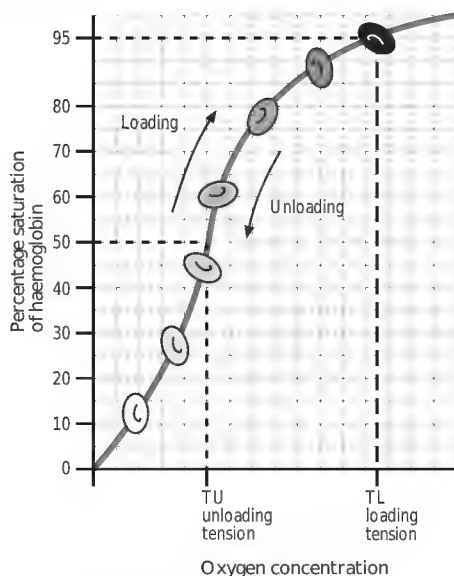
Gas exchange at the tissues is opposite to that at the lungs with oxygen being released and carbon dioxide taken up. Tissues vary widely in their demands for oxygen and in their production of carbon dioxide, particularly during exercise when the muscles become more active. The low oxygen partial pressure in the muscles during exercise increases the diffusion gradient between them and the red blood corpuscles, thus encouraging the dissociation of the oxyhaemoglobin and the release of oxygen in solution to diffuse to the tissues.

Fetal haemoglobin, found in the blood of the fetus developing in the uterus of the pregnant female, has a greater affinity (attraction) for oxygen than the adult haemoglobin of the mother, and thus can 'rob' it of oxygen, ensuring a good supply of oxygen to the developing fetus.

Myoglobin, found in skeletal muscle fibres, has a greater affinity (attraction) for oxygen than haemoglobin in the red blood corpuscles of the blood, and thus can 'rob' it of oxygen, ensuring a good supply of oxygen to the active muscles.

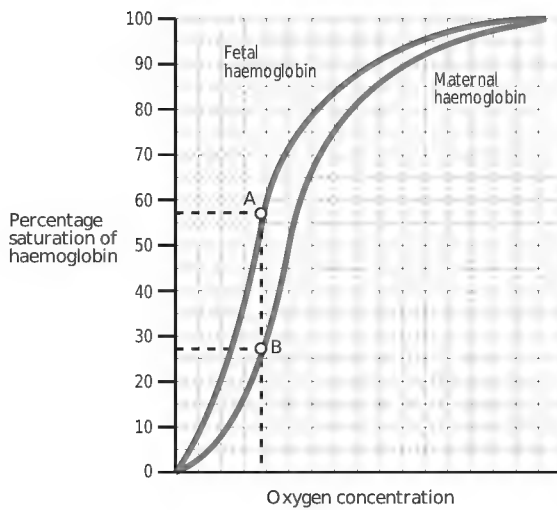
Some carbon dioxide is carried in the red blood cells in combination with haemoglobin as carbaminohaemoglobin. Some carbon dioxide is carried in the plasma in simple solution, but most is carried as hydrogen carbonate ions in the plasma. Carbon dioxide released as a waste product of cellular respiration enters the red blood cells where the enzyme carbonic anhydrase catalyses the formation of carbonic acid, which dissociates into hydrogen ions and hydrogen carbonate ions. The hydrogen carbonate ions enter the plasma to be carried to the lungs. The release of hydrogen carbonate ions into the plasma from the red blood corpuscles is balanced by the uptake by the red blood corpuscles of chloride ions from the plasma (the chloride shift). When the blood reaches the alveolar capillaries these events are reversed, hydrogen carbonate ions enter the red blood corpuscles, carbon dioxide is released to be breathed out, and chloride ions return to the plasma.

Haemoglobin association/dissociation curve

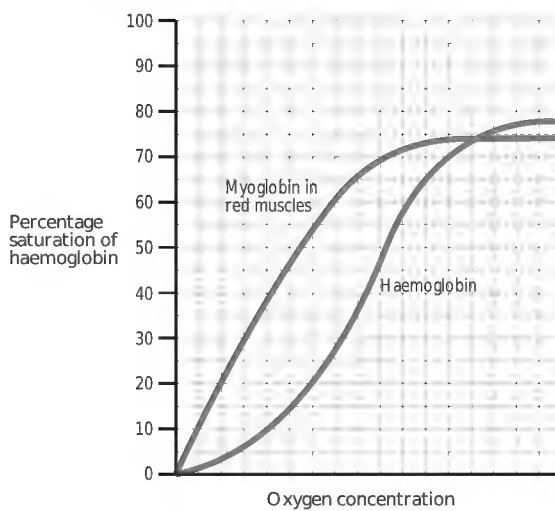


This basic type of curve is altered with differing conditions

Fetal and maternal haemoglobin

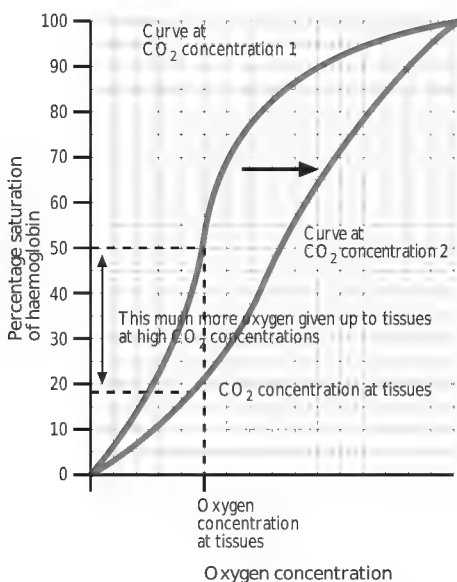


Myoglobin and haemoglobin



The effect of carbon dioxide on oxygen transport by haemoglobin (the Bohr Effect)

As has been described the red blood cells are involved in both oxygen and carbon dioxide exchanges and transport, each of which influence each other. At the tissues, the carbon dioxide, produced as a waste product of aerobic respiration in the mitochondria, diffuses in solution down its concentration gradient, from the high $p\text{CO}_2$ in the mitochondria to the lower $p\text{CO}_2$ in the blood. The greater the difference in $p\text{CO}_2$ the greater the amount of diffusion. The formation of carbonic acid (and lactic acid in anaerobic respiration) lowers the pH of the blood. Any increase in acidity (decrease in pH) and/or increase in temperature encourages oxyhaemoglobin to release its oxygen to the tissues. The way in which oxygen is held and released by haemoglobin at different partial pressures can be represented by an oxygen association/dissociation curve, and an increased tendency by oxyhaemoglobin to release its oxygen is shown by the oxygen association/dissociation curve shifting to the right. This effect is called the **Bohr shift** and its significance is that the more active the tissue (e.g muscle) the more carbon dioxide, lactic acid, and heat are produced and the more oxygen is released to that tissue.



◆ CHECKPOINT SUMMARY

- ◆ Reversible combination of haemoglobin and oxygen in the capillaries of the pulmonary circulation is a physical association.
- ◆ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor.
- ◆ Gas exchange at tissues is in effect the reverse of that at the lungs similarly explained in terms of diffusion gradients (partial pressure gradients).
- ◆ Bohr effect applies to conditions in tissues illustrates how conditions of increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ◆ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen. Note that the placental artery is some distance from the lungs of the mother and therefore not particularly well oxygenated.
- ◆ Myoglobin is a pigment found in red (endurance type) muscle fibres and has a greater affinity for oxygen than does haemoglobin, so that it is capable of loading up high with oxygen from relatively lower saturated haemoglobin. It acts as an intermediary between oxygen in the blood and the muscle fibres.
- ◆ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.

2H.3

Human Ecology

Content:

Adaptations to extreme environments

- ▼ The effects of extremes of environmental temperature and of life at high altitude.

Extremes of temperature

- ▼ Normal body temperature and diurnal variation.
- ▼ The structural, physiological and behavioural mechanisms of temperature regulation, including the structure and roles of the skin, and the roles of thermoreceptors and the hypothalamus.
- ▼ The causes and effects of heat stress, including salt loss, heat cramp, moderate and severe dehydration.
- ▼ The differences between acclimatisation in a visitor and adaptation in a native.
- ▼ The causes and effects of cold stress, including cold injury, trench foot and frostbite, wind chill and exposure leading to hypothermia.

High altitude

- ▼ The environmental conditions in high mountains, including low atmospheric pressure, low temperature, low humidity, high winds and increased solar radiation.
- ▼ The physiological effects of high altitude including hypoxia, hyperventilation, changes in lung volume and pulmonary diffusing capacity, increased red cells and haemoglobin concentration, initial increase in cardiac output.
- ▼ The effects of high altitude stress, including the general symptoms of mountain sickness, increased secretion of antidiuretic hormone, redistribution of body fluids, and impairment of mental reactions.
- ▼ The differences between acclimatisation in a visitor and adaptation in a native.

Introduction

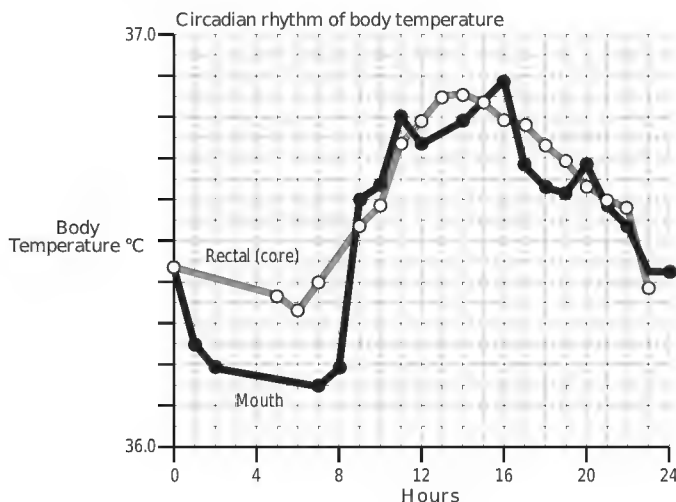
Archaeological and genetic evidence strongly suggest that modern humans, *Homo sapiens*, and their ancestors, evolved in sub-Saharan Africa. The environmental conditions in the savanna regions where humans evolved included high daytime temperatures (exceeding 40°C), cool nights (but with temperatures always above freezing), moderately low humidities and relatively high atmospheric pressure of oxygen. In view of this it is not surprising that in biological (physiological) terms humans are exceptionally well adapted to hot conditions yet rather poorly adapted to cold conditions and the conditions experienced at high altitude. In spite of this, behavioural or cultural adaptations of humans have allowed the species to exploit almost every natural habitat of the world: a larger range than any other single species.

Normal body temperature and diurnal variation

Humans, in common with birds and other mammals are **endothermic**, in other words, they generate their own heat energy and are capable of maintaining a relatively constant body temperature despite wide fluctuations in their surroundings. This allows the biochemical reactions in body cells to proceed at optimum rates, unaffected by temperature changes.

Changes in body temperature do occur but only between narrow limits around the normal 37°C. Daily (**diurnal**) fluctuations in body temperature coincide with periods of rest and activity, the temperature rising during the day when a person is active, and falling at night whilst asleep, and varying from around 36 to 37°C. Daily rhythms like this are called **circadian** rhythms. In menstruating women, a monthly rhythm occurs whereby the average body temperature rises during the last half of the cycle.

Whilst it is possible for the body to survive a 10°C drop in temperature, it can be fatal for the temperature to rise by as little as 4°C. At high temperatures, nerve function is impaired and some enzymes are denatured, stopping vital reactions in cells. It is important, however, to distinguish between the '**core**' temperature of the body, to which these figures relate and the '**shell**' of the body which comprises the skin and underlying tissues. The shell temperature may vary much more with the surroundings because it is not perfectly insulated.



Heat transfer between the body and the environment can occur by any of the following mechanisms:

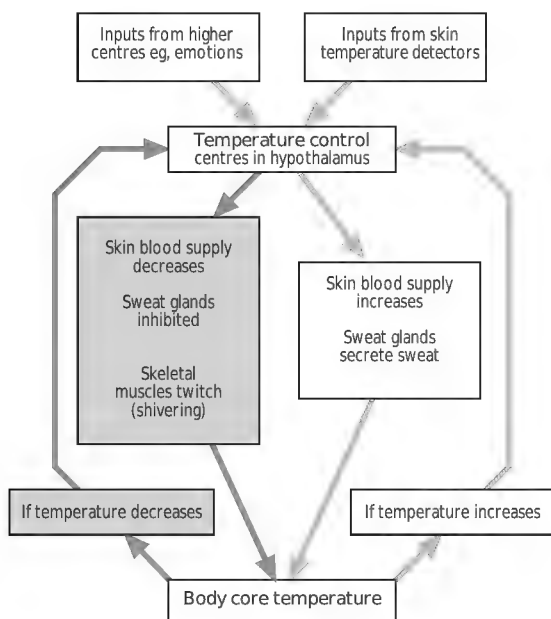
Radiation: For example heat is lost by radiation to the air from the skin surface when the external temperature is less than that of the skin.

Conduction: Direct transfer of heat from warm to cold materials, including air and water. For example heat may be gained by the skin from the water in a hot bath. Heat loss to the air layer surrounding the skin by conduction is increased by air movements such as those created by **convection**. (convection is the process whereby warm air rises to be replaced by colder air moving in to replace it).

Evaporation: A large quantity of energy is required to change water from a liquid to a gas (2.42kJ for every gram of water). This energy (latent heat of vaporisation) is absorbed from the surface when water evaporates. The skin and respiratory surfaces therefore cool whenever water evaporates from them.

The structural, physiological and behavioural mechanisms of temperature regulation, including the structure and role of the skin, and the roles of thermoreceptors and the hypothalamus.

Changes in body temperature are detected both in the skin and the internal body organs by receptors (**thermoreceptors**) linked to the nervous system. Information is processed by a part of the brain called the **hypothalamus** which directs corrective responses, e.g. sweating, shivering, via nerves to the various **effectors** (sweat glands, arterial muscle etc). The hypothalamus can be thought of as the body's thermostat regulator. It controls the involuntary physiological mechanisms by which the body core is maintained at a constant temperature. It should not be forgotten that the conscious parts of the brain (cerebral hemispheres) are also alerted by the thermoreceptors to fluctuations in core temperature and by skin receptors to the external conditions. By this means a person can take voluntary corrective measures, for example, a change of clothing, position or activity. Such responses are called **behavioural mechanisms** of temperature control.



Unit 2H: Exchange, Transport and Reproduction in Humans

There are two sets of sensors or receptors in the body which can detect temperature changes both of which are modified nerve endings and hence part of the nervous system. They are known as thermoreceptors.

Firstly there are thermoreceptors in the hypothalamus of the brain which sense the temperature of blood passing through it (the core temperature) and detect deviations from this temperature, however slight. To make the process more sensitive the hypothalamus has separate heat and cold receptors located in the heat loss and heat gain centres. Stimulation of sensors in both the hypothalamus and skin generate signals in the nervous system which then stimulate appropriate effectors (see below). When cold receptors have been stimulated, effectors are stimulated which increase heat gain and decrease heat loss. When heat receptors have been stimulated, effectors which allow increased heat loss or decreased heat gain are stimulated.

The second set of thermoreceptors, also including both heat and cold receptors, are in the skin. These detect changes in the environmental temperature and send nerve impulses to the hypothalamus which then processes the information and sends an appropriate signals to effectors. They also send nerve impulses to the cerebral hemispheres of the brain allowing the person to be conscious of being warm or cold. This can trigger some of the behavioural responses discussed below.

Physiological mechanisms of temperature control are directed by the hypothalamus and are not under conscious control. The effector organ for these control mechanisms is the skin.

Whilst the skin has a number of roles in the body, many of its structures are of vital importance in temperature regulation. In outline these include:

- ▼ **Sweat glands** connected to sweat pores produce sweat and secrete it onto the skin surface. As sweat evaporates it removes heat from the skin (the latent heat of vaporisation).
- ▼ **Blood capillaries** form a dense network throughout the dermis. The flow of blood through the capillaries is controlled by arterio-venous shunts. When blood is diverted to surface capillaries there is an increase in heat loss by radiation, conduction and convection.
- ▼ **Thermoreceptors (hot and cold)** are nerve endings which act as temperature sensors, detecting changes in air temperature and transmitting this information to the hypothalamus.
- ▼ **Adipose (fat) tissue** lying below the dermis provides thermal insulation, preventing excess heat loss from the body.
- ▼ **Sebaceous glands** produce an oily secretion (sebum) which waterproofs the skin and hair and reduces water loss from skin cells.
- ▼ **Erector pili muscles** contract to raise the hairs at the base, in order to trap a layer of still air next to the skin and reduce heat loss; however with the reduction of body hair and the adoption of clothing this function is redundant in humans. The contracted erector pili muscles produce the familiar 'goose-pimples' seen on the skin when cold or emotionally stimulated.

Heat Gain

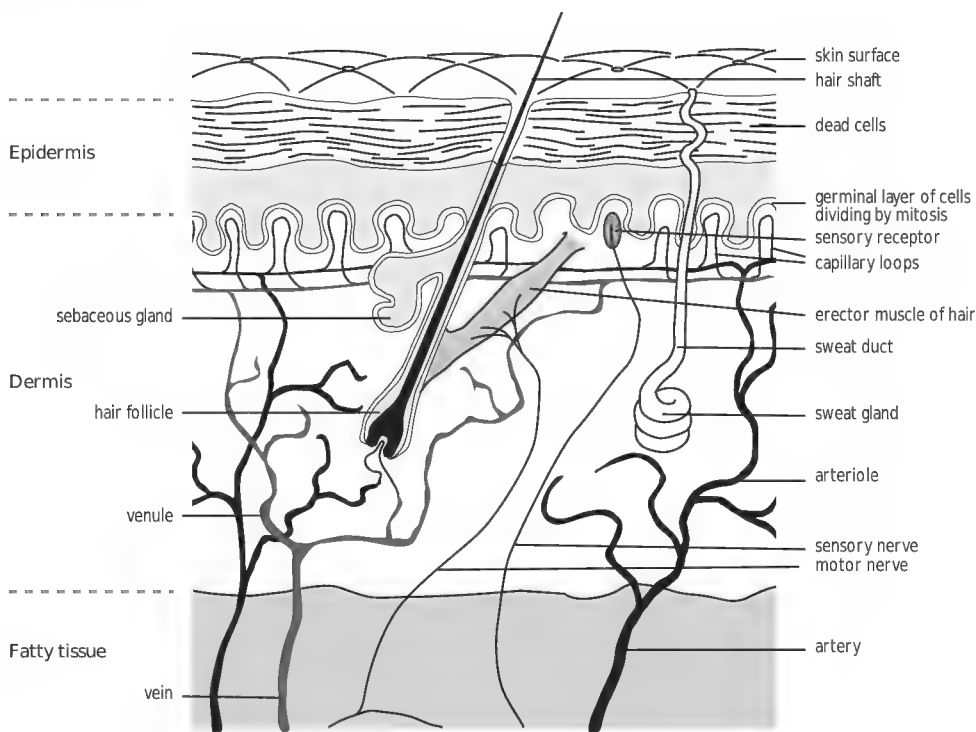
Heat may be absorbed from the surroundings, for example by taking a hot bath or sitting in the sun, but it can only be generated in the body by respiration and so the most important means of increasing heat production is by exercise which raises the rate of respiration in the skeletal muscles. Heat from respiring tissues and organs is circulated around the body, and from the core to the shell, by means of the circulating blood.

In cold conditions, the **shivering** reflex may be triggered by the hypothalamus. This is an involuntary response by which skeletal muscles are stimulated to contract rhythmically, generating heat in the process.

Heat loss

The human body loses heat to the environment by the physical processes of conduction, convection, radiation and evaporation. Whilst the first three depend on the environment being colder than the person, evaporation does not. This is therefore the only means of heat loss available when the air temperature exceeds 37°C.

The most important regulatory mechanisms for temperature control are **sweating** and **vasodilation**, both of which allow the body to lose excess heat generated by exercise or absorbed from warm surroundings.



In general, heat is generated in the core and transferred to the shell by arterioles which supply the capillary beds of the skin and underlying tissues. The volume of blood to the shell, and consequently the amount of heat transfer, can be regulated by means of the involuntary (smooth) muscles which line the walls of these arterioles. **Vasoconstriction** is a narrowing of the arterioles by contraction of the muscular wall, **vasodilation** is a widening of the arterioles by relaxation of the muscular wall. When the body needs to lose heat, more blood is shunted to the shell by vasodilation. The increased blood supply causes the skin to change to a red colour and heat is lost by radiation from the surface.

Sweating is a very effective way of losing heat provided that the fluid evaporates directly from the skin surface and does not run away or soak into clothing. Theoretically the evaporation of 1 litre of sweat can remove 2500kJ of heat from the body, and sweat may be lost at the rate of several litres per hour, but even during moderate exercise or on a warm humid day the loss of fluid may be potentially harmful. Sweat is a dilute solution containing salt, so sweating can cause both dehydration and an electrolyte imbalance if the water and salt are not replaced by appropriate nutritional intake.

The choice of clothing for different activities and conditions is very important. Clothing acts as an insulating layer between the skin and the external environment, trapping a layer of air. The more air layers, the more insulation. It is important that clothing should be loose in order to preserve the air layers and to allow air movement. Light colours reflect radiant energy from the sun whilst dark colours absorb radiant energy. Loose fitting light coloured clothes are best for hot climates as they also allow effective sweating to occur at the skin surface.

THE CAUSES AND EFFECTS OF HEAT STRESS, INCLUDING SALT LOSS, HEAT CRAMP, MODERATE AND SEVERE DEHYDRATION

The causes and effects of heat stress.

Between 25°C and 30°C body temperature is regulated entirely by means of changes in blood flow from core to shell. This range is called the **thermoneutral zone**. Below 25°C, the body must increase its heat production by muscular activity. Above 30°C, sweating occurs. If the external temperature rises above the normal body temperature (37°C), then the body will absorb excess heat from its surroundings unless it is completely insulated.

Whilst the body is well adapted to deal with high temperatures, prolonged exposure to heat can place a stress on the body, preventing it from functioning in an optimum fashion. Basically **heat stress** occurs when the rate of heat gain by the body (by transfer from the environment and from metabolic reactions) exceeds heat loss by sweating and other means.

The rate of heat loss by evaporation is affected greatly by the relative humidity. Most people can tolerate temperatures of 40°C without discomfort if the air is dry, but will suffer from heat stress at this temperature if the relative humidity rises. **Heat stress** is related to loss of fluid through sweating. This is a common problem in people undertaking hard physical work in tropical regions.

In its mildest form heat stress is referred to as **heat exhaustion** and characterised by a drop in blood pressure (hypotension) brought on by a loss of blood fluid volume and the shunting of blood to the shell. If the conditions causing heat stress are prolonged, then the temperature control mechanisms may break down altogether resulting in delirium and unconsciousness. This is called **heat stroke** and can quickly lead to death if the conditions are not reversed.

Salt loss and heat cramp

As salt is lost from the body in sweat, the concentration of sodium in the extracellular fluid decreases. This can lead to the development of painful muscle cramps, which are related to the fact that sodium plays a major role in conduction of nerve impulses and muscle contraction. Muscle cramps occur in the same way whether there has been a net loss of both water and salt from the body, or simply a net loss of just salt with an adequate supply of pure water.

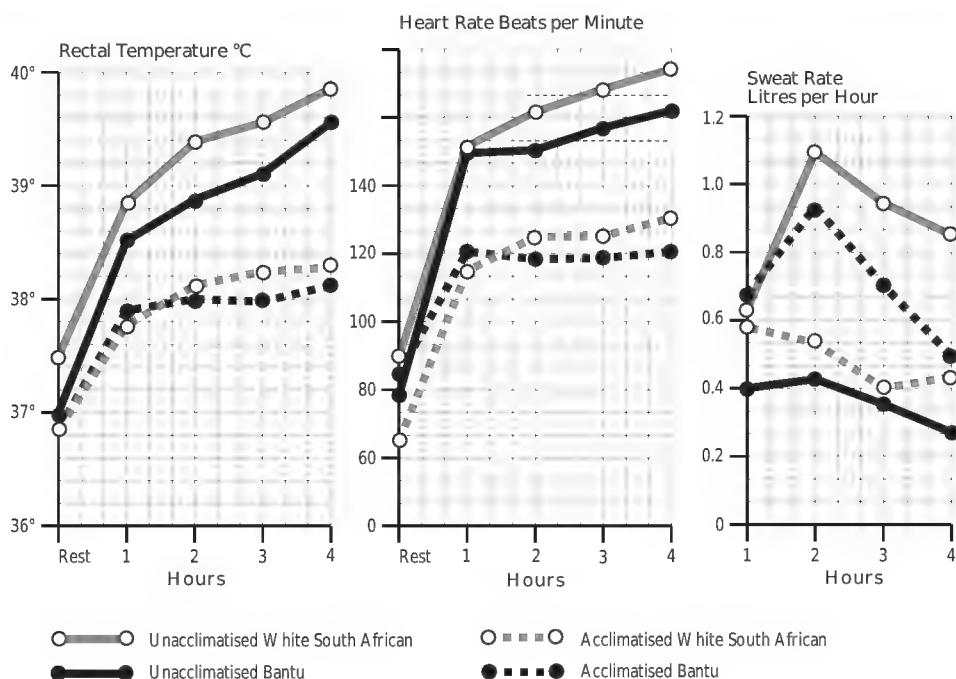
The effects of water loss (dehydration)

Sometimes known as heat exhaustion, common symptoms of this are giddiness, fatigue, and weakness. In more severe cases it can lead to hypotension (low blood pressure brought about by the increased blood flow to skin and reduce blood volume through water loss) and to an increase of body temperature as the rate of sweating cannot meet the demand for heat loss. If this progresses, serious dehydration and delirium, loss of consciousness and even death may follow. This is often experienced by troops who undertake heavy exercise in hot climates without being acclimatised. (It should be noted that as dehydration progresses individuals become less aware of the sensation of heat and will not take measures to avoid heat gain, aid heat loss or rehydrate themselves.) It is generally said that a loss of more than 10% of total body water will result in death.

The differences between acclimatisation by a native and adaptation in a visitor

Acclimatisation is the process whereby individuals adapt physiologically to environmental conditions different to those they are used to. Thermal acclimatisation (acclimatisation to heat) has been well studied. When an individual from a colder region moves into a hotter region he/she will spend 10-20 days acclimatising to the heat. Within this time a number of physiological changes occur which will allow the person to tolerate heat to a similar extent to a native person. Acclimatisation will produce the following changes:

- ▼ Decreased core temperature
- ▼ Decreased resting heart rate
- ▼ Increased rate of sweating and earlier onset of sweating
- ▼ Decreased salt loss in sweat



It should be noted that the extent of acclimatisation depends on the external temperature and the degree of activity. Thus to be fully acclimatised to manual work at 40°C a person must perform manual work at 40°C. Resting at 40°C or working at 35°C will not produce the full acclimatisation response. Acclimatisation to heat will be rapidly lost if the hot conditions are not experienced on a regular basis, but it is thought that it can be regained more rapidly on second exposure.

There is some argument as to whether non-native people can achieve the same tolerance of heat as those native to hot regions. Some studies claim that individuals who have been brought up in hot environments will have a greater number of active sweat glands, than those brought up in colder climates, and therefore have a slight advantage in heat loss by sweating. Differences in body size and shape and the amount of body fat will also play a role in heat tolerance. The large surface area to volume ratio (caused by long limbs) and the low body fat of native Africans may help to increase heat loss. Differences in physical fitness are also important.

The causes and effects of cold stress, including cold injury, trench foot and frostbite, wind chill and exposure leading to hypothermia.

As discussed above, humans are essentially a tropical species who could not tolerate most habitats outside the tropics without their extensive behavioural mechanisms to allow heat gain and prevent heat loss. Physiologically and anatomically humans are not well adapted to cold temperatures, and will suffer from a range of cold related injuries on exposure to prolonged cold temperatures. Cold stress occurs when the rate of heat loss exceeds the rate of heat gain by metabolic processes and behavioural means.

Cold injury, frostbite and trenchfoot

During prolonged exposure to extreme cold, physical injury to tissues may occur. This is generally limited to the skin and surface tissues of the extremities (hands and feet) where blood flow is reduced owing to the body's need to maintain a constant core temperature, and skin temperature may be close to environmental temperature. Some parts of face may also be affected since it is more likely to be directly exposed to the outside air.

Frostbite is defined as the formation of ice crystals in the skin and surface tissues (and more rarely muscle and bone) owing to a temperature of less than -3°C in that region. For this to occur, the outside temperature must usually be at least -6°C . Frostbite usually affects the fingers and toes, and because the individual has often lost feeling in the extremities he or she may not notice its development. Since frostbite kills the affected tissue this will eventually blister, turn black and be lost. Any remaining tissue is in danger of becoming infected, leading to gangrene, and perhaps death. Many mountaineers and arctic explorers have lost parts of their fingers and toes to frostbite either during expeditions or on return when parts have had to be surgically removed to prevent infection.

A related condition, known as **trenchfoot**, occurs in the extremities following prolonged exposure to cold (but not freezing) water. Rarely seen since the first world war, when it affected soldiers standing in wet trenches, this condition leads to deterioration of the tissues which may become infected.

Hypothermia

Hypothermia is defined as a fall in the core body temperature below 35°C . In mild hypothermia (the range from 32 – 35°C) the person feels intensely cold, is alert, and attempts to warm up. If core temperature falls below 32°C (severe hypothermia) the person's mental state, including judgement of the conditions, and awareness of the cold is affected. S/he may go into a coma and death can follow, usually caused by severe irregularities of heart beat, brought on by changes in the respiratory rate of the contracting cardiac muscle.

Hypothermia occurs in three main situations:

- ▼ During prolonged exposure to extremely cold weather conditions, such as those encountered during high altitude mountaineering or expeditions in the Arctic and Antarctic. In these circumstances heat production cannot keep pace with heat loss. Hypothermia in these conditions is much more likely

if it is wet and windy. Wind has the effect of lowering the effective temperature and will rapidly evaporate water from wet clothes, so cooling the skin.

- ▼ Following long periods of immersion in water at 20°C or less, such as following an accident at sea.
- ▼ In the home environment of houses in cold climates with limited heating. Hypothermia is most common in inactive people (especially the elderly) and in those with a low level of body fat and a high surface area to volume ratio (especially babies). Some drugs may also contribute to the effect.

High Altitude

Over 25 million humans live at altitudes between 2500m-5500m on the mountain plateaus of Ethiopia, South America (the Andes) and Tibet (the Himalayas) in spite of several physical stresses associated with these environments. Of these the most severe stress for human populations is the reduced partial pressure of oxygen which effectively prevents permanent habitation above 5500m. (Although humans can of course survive for short periods of time, without extra oxygen, at altitudes above 8000m, as demonstrated by the ascent of Everest).

The relevant specific features of mountainous regions are:

- ▼ Low atmospheric pressure. At 5000m the atmospheric pressure is half that at sea level. This results in lower partial pressure of oxygen in the air and consequently in the alveoli and blood of humans. This affects the association and dissociation of haemoglobin and oxygen, the ability to transport oxygen around the body, and hence the ability to do work.
- ▼ Low temperatures for part or all of the year, particularly at night due to reduced cloud cover. Temperatures often fluctuate enormously over the year. For example, in the Himalayas day-time temperatures in summer may exceed 40°C whilst in winter they can drop to -40°C. A short growing season (4 months) limits food production.
- ▼ Low humidity. This is related to low atmospheric pressure as the air has a lower capacity to hold water vapour. Along with high wind speed this can increase the rate of water loss by evaporation leading to dehydration and heat stress. Low humidity also contributes to low rainfall with effects on plant growth and human nutrition.
- ▼ High wind speeds which increase the cold stress by adding a wind chill factor. This can increase the risk of hypothermia. High winds also increase evaporative water loss as discussed above.
- ▼ Increased solar radiation. Owing to the reduced air pressure and humidity UV rays penetrate the atmosphere more easily. This can lead to high temperatures at times of the year, and can lead to burning of the skin even when temperatures are low.

◆ CHECKPOINT SUMMARY

- ◆ Extremes of environmental temperature pose problems for the body's homeostatic mechanisms which strive to keep the core temperature at the optimum (normal) 37°C.
- ◆ Homeostasis is a dynamic equilibrium 'hunting' around the optimum
- ◆ In addition even under constant optimum external conditions when at rest, there are diurnal (daily) variations of body temperature as a result of diurnal rhythms of brain and hormonal activity.
- ◆ The skin has thermoreceptors and detects the heat gradient between it and the surroundings, and the hypothalamus of the brain measures the body temperature against the target of 37°C.
- ◆ Blood vessels in the skin are dilated or constricted according to the need to lose more or less heat over the skin by conduction, convection and radiation.
- ◆ Sweat glands secrete sweat onto the surface of the skin to lose heat by evaporation (latent heat of evaporation).
- ◆ Heat stress is caused the body attempting to regulate the core temperature in a hot climate without adequate supplies of water and electrolytes (salts).
- ◆ Sweating results in the loss of water leading to moderate or severe dehydration if not replaced, and the associated loss of salts can lead to heat cramps.
- ◆ Visitors to hot climates can acclimatise after a period as a result of an increase in efficiency of the heat regulating mechanisms.
- ◆ People native to the conditions are adapted genetically to low body fat, and large surface area to volume ratio.
- ◆ The body can withstand a greater drop of temperature than it can a rise, because with a drop in temperature metabolism slows so damaging processes are also slowed.
- ◆ Windchill and exposure lead to hypothermia and below a certain critical temperature the circulation to the extremities and the limbs is shut down in order to conserve the core temperature.
- ◆ The reduction in blood flow leads to cold injury, trench foot and frostbite.

The physiological effects of high altitude

Individuals at altitudes above about 2500m suffer from **hypoxia** (a condition where the oxygen content of the blood is too low to allow adequate aerobic respiration in tissues). The effects of hypoxia can be divided into acute hypoxia experienced within minutes or hours of entering a high altitude region and chronic hypoxia experienced by residents and long term visitors who have become acclimatised to high altitude regions.

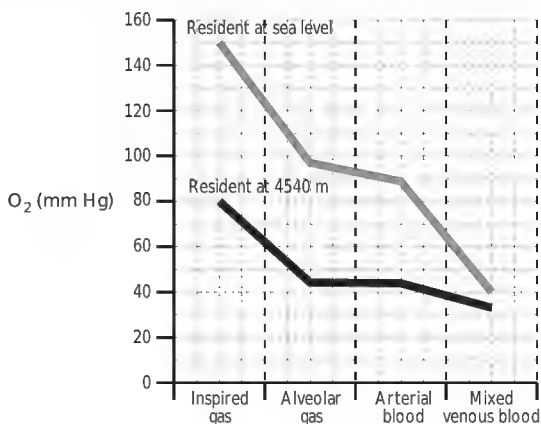
Hyperventilation and changes in lung volume

One of the earliest symptoms of hypoxia is an increase in the rate and depth of breathing (hyperventilation) brought about by a low partial pressure of oxygen in the alveoli of the lungs. This functions to allow more oxygen to enter the lungs. It should be noted that another effect of this is to increase the excretion of carbon dioxide from the alveoli. Low pp of CO_2 in the alveoli and blood causes a decrease of breathing rate. These opposing effects can lead to unpleasant cycles of fast and slow breathing in the first few days at altitude. Over time, however, the body achieves a stable, increased, respiratory minute volume (amount of air breathed per minute).

Pulmonary diffusing capacity

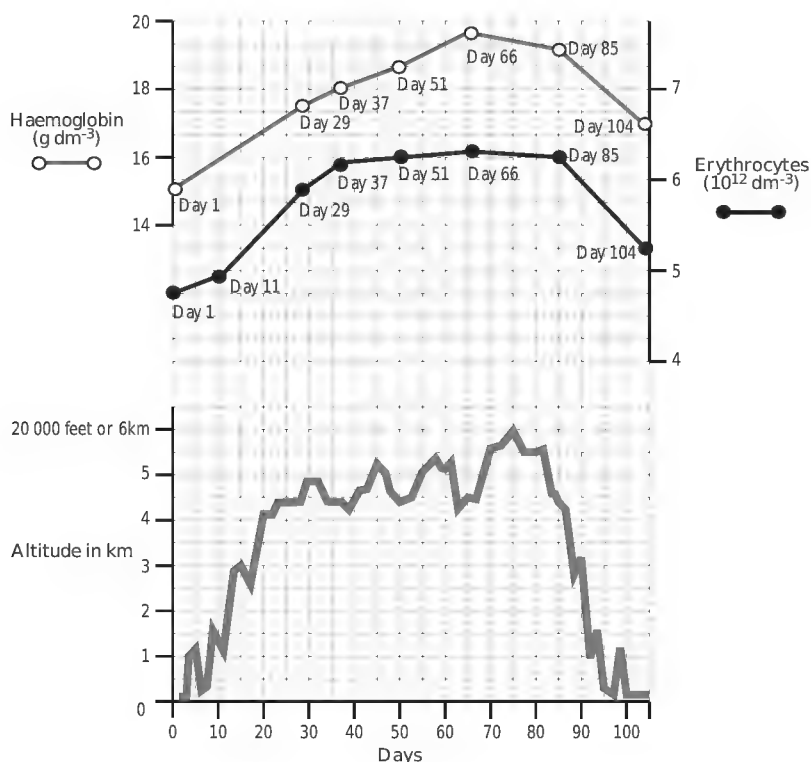
Hypoxia can sometimes lead to **pulmonary oedema** where the tissues surrounding the capillaries of the lungs (including the alveoli) become swollen with excess tissue fluid. This is thought to result from increased blood pressure which forces extra fluid out of capillaries at the arterial end and prevents it from moving back into the capillaries at the venous end. When fluid accumulates around the alveoli it increases the distance between air spaces and the blood, and hence reduces the diffusing capacity of oxygen into the blood and carbon dioxide out of the blood. This can lead to breathlessness.

Oxygen levels at different altitudes



Increased number and haemoglobin content of red blood cells

Low partial pressures of oxygen in the blood stimulate the release of the hormone erythropoietin from the kidney which increases the rate of production of red blood cells. Red blood cell numbers may almost double in extreme cases. The haemoglobin content of each RBC and therefore the total haemoglobin in the blood also increases, improving oxygen transport around the body. This effect, and the effect of increased density of capillary networks in the tissues is often exploited by endurance athletes who train at high altitudes for period of several weeks or months. On their return to sea level they will experience temporary improvements in aerobic performance.



Increased cardiac output

Acute hypoxia causes a rapid increase in heart rate and hence cardiac output (heart rate x stroke volume). This improves oxygen delivery to the tissues. Over prolonged periods at altitude, heart rate is gradually reduced to values close to normal at sea level. This may be due to the improved oxygen carrying capacity of the blood and increased density of capillary networks in tissues.

High altitude stress: mountain sickness and other effects of high altitude

Mountain sickness is a term used to describe signs and symptoms experienced by some people at altitudes above 3500m. These can include nausea (feeling sick), headaches, lethargy, dizziness, diarrhoea, and psychological disturbance. In severe cases acute pulmonary oedema and or cerebral oedema (accumulation of fluid in the tissues of the brain) can occur which may be fatal. The exact cause of mountain sickness is not clear but includes both hypoxia and dehydration. Individuals vary widely in their tendency to develop symptoms, and these variations are not related to physical fitness or health.

At altitude there tends to be an increase in the quantity of anti-diuretic hormone (ADH) secreted by the posterior pituitary gland in response to a reduction of water levels in the blood. ADH helps to conserve body water by allowing increased reabsorption of water in the kidney, and hence production of smaller volumes of concentrated urine. Water levels of the blood may be reduced at altitude for several reasons: firstly high wind speeds, dry air and sometimes intense solar radiation increase the rate of evaporation of sweat from the skin (and possibly from the lungs and mouth/nose as breathing rate increases) and secondly, water may be scarce and intake lower than necessary.

It is very important for the body to maintain a constant water level and hence volume of blood. If blood volume falls then blood pressure will fall and the exchange of materials between blood and tissue fluid (interstitial fluid) will be affected. To help to prevent this water may move from the intracellular compartments of the body (i.e. within cells) into the extracellular fluid (blood and tissue fluid).

Hypoxia can affect brain function in a number of ways even at moderate altitudes. Affects include poor judgement, slower reaction times, poor co-ordination, impairment of short term memory and learning skills. Severe hypoxia can cause permanent brain damage (as experienced in babies deprived of oxygen at birth) and in some mountaineers. It may also result in coma and death.

Acclimatisation and adaptation to high altitude

In contrast to the ease with which humans acclimatise to high temperatures, it is difficult to acclimatise to the chronic hypoxia of high altitudes. Visitors, even those who stay for months or years, never become as well adapted to the environment as natives. However, as described above, acclimatisation to altitude, does occur. Changes in respiratory volume, RBC number, and haemoglobin content of RBCs begin almost immediately and continue over weeks and months at altitude. Acclimatisation is often best achieved by gradual ascent to altitude. Therefore a person who climbs up to the high plateaus of the Himalayas or Andes is often spared the effects of acute mountain sickness whereas one who flies in to such a place could experience severe effects.

High altitude natives are thought to possess genetic and developmental adaptations to high altitude as well as the benefits of acclimatisation. One striking feature is a barrel shaped chest providing increased lung size and volume. Coupled with this, such individuals have very high values of $\text{VO}_2 \text{ max}$ (maximal value of oxygen uptake per kg of body mass per minute), a measure of the ability to do physical work. The $\text{VO}_2 \text{ max}$ of natives can never be equalled by non natives, even those who spend many years at altitude. It is interesting to note that whilst an acclimatised non-native individual has an improved $\text{VO}_2 \text{ max}$ when he returns to sea level, a native does not.

A further genetic adaptation of high altitude natives is a dark skin colour to reduce skin damage by the high levels of UV light.

◆ CHECKPOINT SUMMARY

- ◆ In high mountains there is low atmospheric pressure, low temperature, low humidity, high winds and increased solar radiation.
- ◆ The low atmospheric pressure means that there is a proportional drop in oxygen content leading to insufficient oxygen in the blood (hypoxia).
- ◆ The thinner air and lack of oxygen leads to hyperventilation, a decrease in lung volumes and in pulmonary diffusing capacity. Above 1600m maximum oxygen uptake decreases by about 10% for every 1000 m increase in altitude.
- ◆ There is an initial increase in cardiac output to increase the blood supply to the lungs and the tissues of the body.
- ◆ After a longer period increased secretion of the hormone EPO increases the number of red blood cells and haemoglobin concentration to compensate for the lower external oxygen levels.
- ◆ High altitude stress includes the general symptoms of mountain sickness, increased secretion of anti-diuretic hormone (ADH) and consequent retention of fluid, redistribution of body fluids and impairment of mental reactions.
- ◆ After a period visitors acclimatise as a result of the changes in the red blood count and efficiency of breathing, and those native to altitude are adapted permanently with high blood counts.

2H.4

Human Reproduction & Development

Contents

Reproduction

- ▼ The structures and functions of the male and female reproductive systems.
- ▼ Meiosis and its significance as the division of a diploid nucleus to give haploid nuclei; the behaviour of chromosomes during the first and second divisions of meiosis including chiasmata formation.
- ▼ The production of gametes in oogenesis and spermatogenesis.
- ▼ The events in the menstrual cycle; the roles of luteinising hormone, follicle-stimulating hormone, oestrogen and progesterone.
- ▼ The transfer of male gametes leading to fertilisation.
- ▼ Implantation; the functions of the placenta in relation to the development of the embryo; the role of the placenta in controlling the passage of potentially harmful substances, illustrated by reference to nicotine, alcohol, heroin and viruses such as HIV and rubella.
- ▼ The stages of birth and the control by fetal and maternal hormones.
- ▼ Colostrum and milk production; the control of milk production by prolactin and oxytocin.
- ▼ The importance of colostrum.

Development

- ▼ Human growth curves, including changes in the proportions of body parts from birth to maturity.
- ▼ The effects of ageing on the skeletal system, illustrated by osteoarthritis and osteoporosis; on the cardiovascular system and reproductive systems, illustrated by the menopause and HRT.

The male gamete producing organs (**testes**) have two functions. Firstly, the production of haploid male gametes (sperm) capable of fertilising an ovum and so passing on the male's genes into a new generation. Secondly, the production of male hormones, particularly testosterone. This allows the development of the secondary sexual characteristics of the male and is also needed for sperm production and sexual activity. Both functions are performed in the **seminiferous tubules** which are packed into lobules inside each testis. **Spermatogenesis** (the production of sperm discussed later) occurs in the walls of the tubules whilst testosterone is secreted by cells in between the tubules (interstitial cells). The testes lie outside the body in the **scrotum**. The function of this is to keep the testes slightly cooler than body temperature (about 35°C) for optimal sperm production.

Diagram illustrating the male reproductive system and associated structures. The diagram shows the internal organs and their connections to the external genitalia (penis and scrotum).

Labels on the left side (top to bottom):

- bladder
- spermatic cord (sperm duct and blood vessels)
- erectile tissue
- penis
- urethra
- foreskin
- glans
- scrotum

Labels on the right side (top to bottom):

- ureter from left kidney
- sperm duct
- seminal vesicle
- prostate gland
- Cowper's gland

Internal structures labeled in the center:

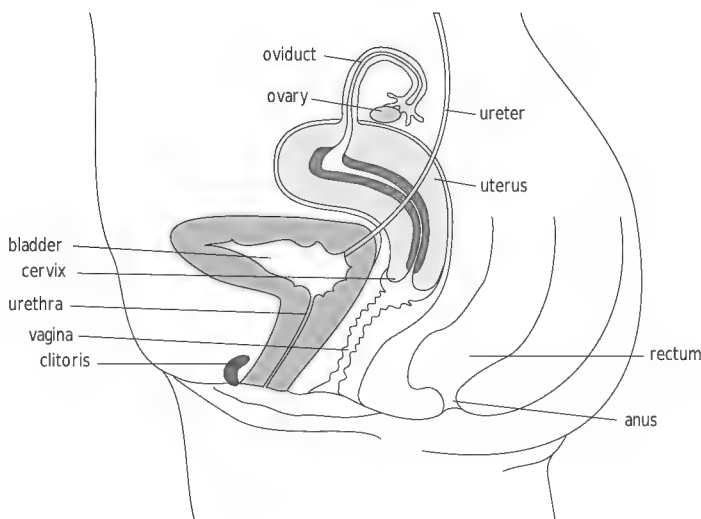
- coiled tubes (epididymis)
- testis

The remaining components of the reproductive system are all concerned with moving sperm from the testes to the **urethra** and into the female reproductive tract during sexual intercourse. The sperm from the seminiferous tubules are transported to the **epididymis**, a long coiled tube where fluid is reabsorbed from the sperm and chemicals secreted which allow sperm to complete their maturation and develop the ability to swim. From here sperm are moved to the sperm ducts (vas deferens), straight tubes which lead to the urethra just below the exit from the bladder.

In order to perform their functions, sperm are mixed with a variety of secretions to form **semen** before they leave the body during ejaculation (see below). The paired **seminal vesicles** secrete a watery alkaline fluid containing sugars (e.g. fructose) for nourishing the sperm. Mucus is also secreted. The **prostate gland** and **Cowper's glands** also secrete alkaline fluid and mucus. The alkaline fluid helps to neutralise any traces of urine present in the urethra and to neutralise the acid environment of the vagina, so providing more suitable conditions for the sperm to function.

The **penis** is used to convey sperm into the reproductive tract of the female during sexual intercourse. It contains **erectile tissue** and a central tube, the urethra through which semen from the vasa deferentia pass. At other times this tube carries urine from the bladder. A system of **sphincter muscles** closes the exit from the **bladder** during sexual activity.

The female reproductive system



The female gamete producing organs (ovaries) lie inside the abdomen. As in the male these have two functions: the production of haploid female gametes (ova) containing genetic information from the female; and the production of female hormones, particularly oestrogen and progesterone.

These control the development of secondary sexual characteristics and, along with hormones from the pituitary gland, control the events of the menstrual cycle.

Close to the border of each ovary is the **oviduct**. The oviducts are narrow tubes whose function is to transport ova released from the ovary to the uterus. The oviducts aid the movement of ova to uterus in two main ways. Firstly they have a fringed funnel which helps to 'catch' the ova and guide them into the oviduct. Secondly they are lined with ciliated epithelial cells which beat and so move the ovum along towards the uterus. Fertilisation usually takes place in the oviduct.

The **uterus** is a muscular organ about 7 x 5 cm in size in a non-pregnant woman whose function is to house a developing embryo. Its wall consists of three layers: an outer covering; a thick middle layer of smooth muscle (the **myometrium**); and the inner **endometrium** containing a dense network of blood vessels and glands. The characteristics of the endometrium vary during the menstrual cycle as discussed below. During pregnancy the uterus can expand to up to 10 times its normal size.

The **cervix** or neck of the uterus is a ring of smooth muscle containing mucus secreting cells which help to provide optimum conditions for sperm survival at around the time of ovulation. The cervix is normally tightly closed but during birth will dilate to allow the baby's to emerge head first.

The **vagina** is a short muscular tube which receives the penis during sexual intercourse. It is lined with epithelial cells secreting vaginal fluids. Like the cervix it must stretch to several times its normal size during birth.

The external female genitalia or **vulva** consists of the **labia majora** and **labia minora** which surround the vaginal opening, opening of the **urethra** and the **clitoris**, a small erectile structure. The clitoris is similar in structure to the penis. Stimulation of the clitoris may result in orgasm.

Glands within the vulva secrete mucus to lubricate the penis during sexual intercourse.

Gamete production (gametogenesis)

During gamete production (gametogenesis) in animals, and in spore formation which precedes gamete production in plants, the number of chromosomes in the nucleus is halved in a process known as **meiosis**, so that normal gametes have half the normal number of chromosomes, that is they are **haploid**. A **diploid** zygote, which has twice the haploid number of chromosomes, is formed by fertilisation. Certain genetic 'mixing' events, which occur during meiosis, and the random fusion of the gametes result in genetic variation in the offspring which may be of adaptive advantage.

Meiosis

Meiosis is a special type of cell division called a **reduction division** in which the number of chromosomes is halved from the diploid to the haploid number. The mechanisms of cell division are very similar to that already described for mitosis.

Meiosis involves two divisions referred to as the first and second divisions (Meiosis I and Meiosis II). Remember that the nucleus of each cell contains two sets of chromosomes; one maternal, from the female gamete and one paternal, from the male gamete. As a result, each chromosome has a partner in the other set which carries genes for the same characteristics. Two such chromosomes are said to form a **homologous pair**.

During interphase, before nuclear division by meiosis starts, the DNA replicates

During prophase I the chromosomes are formed as double structures of a pair of **sister chromatids**. They then pair up with their homologous partners to form structures called **bivalents**. They twist around each other, and breaks occur in the chromatids. A break in one chromatid is matched by another in the corresponding non-sister chromatid. The broken ends rejoin with the ends of the non-sister chromatid resulting in a **crossing over** between non-sister chromatids. The homologous chromosomes begin to repel each other, and the points where crossing over has occurred serve to slow the repulsion and appear as a cross shape (**chiasma pleural chiasmata**). These crossing over points occur in a random fashion serving to reshuffle the genetic pack, mixing the DNA of the maternal and paternal chromosomes. Crossing over during meiosis is an important source of genetic variation in organisms which reproduce sexually.

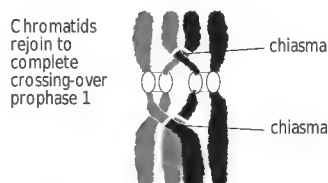
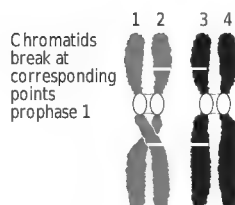
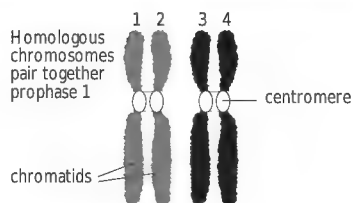
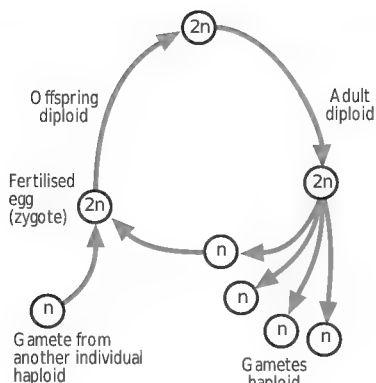
Prophase I may take several days to complete. In metaphase I the chromosomes are pulled to the equator of the cell, held only by the junction points of the chiasmata. They line up on the equator at random, with maternal and paternal chromosomes on either side. During anaphase I the homologous chromosomes pull apart from each other, separating towards the opposite poles of the cell, the completion of which is known as telophase 1.

Crossing over, and the random alignment and separation of maternal and paternal chromosomes, prevents any gametes being formed from being replicas of gametes that formed the original cell undergoing meiosis, and therefore introduces genetic variation into the gametes.

Two new spindles are formed at right angles to the first, one at each pole, and the chromosomes (each composed of two sister chromatids) move to the equator for a second metaphase (metaphase II). From here on the events are similar to those of mitosis as the sister chromatids move to opposite poles, i.e. anaphase II, and telophase II. Cytokinesis results in the formation of four new haploid daughter cells. Note that the result of meiosis is four cells (gametes) each containing half the original number of chromosomes with mixed up sections of maternal and paternal DNA sequences, as well as mixed up sets of maternal and paternal chromosomes.

◆ CHECKPOINT SUMMARY

- ◆ The male reproductive system consists of the testes which produce spermatozoa by meiosis.
- ◆ Copulation transfers them to the female via a system of tubes and erectile tissue.
- ◆ Accessory glands are important in secreting substances essential for successful fertilisation.
- ◆ The female system consists of ovaries which release egg cells (ova) into the abdominal cavity, from where they are swept down the oviducts by ciliated epithelium, into the uterus.
- ◆ The uterus connects to the exterior by the vagina.
- ◆ Offspring result from the fusion of gametes, forming a zygote.
- ◆ This fusion of gametes involves various genetic mixing events and therefore leads to genetic variation in offspring.
- ◆ These genetic mixing events include events in the nuclear division (meiosis) involved in the production of gametes, and in the random fusion of gametic nuclei from different sexes.
- ◆ In the first phase of meiosis (Meiosis I) the two sets of chromosomes pair up, so that chromosomes occur in homologous pairs. Each chromosome is duplicated into two chromatids, so one pair of chromosomes is made up of four chromatids.



Usually 2 or 3 cross-overs affect each chromosome pair. Note cross-overs can occur between 1&3; 1&4; 2&3; 2&4, but not 1&2 or 3&4

◆ CHECKPOINT SUMMARY

- ◆ Meiosis is a reduction division in which the diploid number of chromosomes (two sets) is reduced to the haploid (one set).
- ◆ The homologous chromosomes of a pair entwine, one chromatid of each pair breaks and rejoins with the broken chromatid of the other pair, in a process known as genetic recombination or crossing over.
- ◆ Cross overs are visible under the light microscope and are known as chiasmata (Greek for crosses), they result in the exchange of genes (alleles) between homologous chromosomes.
- ◆ The chiasmata align on the equator of the nuclear spindle apparatus (NSA), before the homologous chromosomes repel each other to opposite poles.
- ◆ Either chromosome of each pair can go to a particular pole, resulting in mixing of the original sets (independent assortment).
- ◆ Two daughter nuclei are thus formed, each with one (haploid) set of chromosomes, with each chromosome composed of two chromatids.
- ◆ The second phase of meiosis (Meiosis II) involves the centromeres of the chromosomes aligning on the equator of a each of two new NSA formed at right angles to the first.
- ◆ The chromatids then repel each other to form four new haploid nuclei.

Spermatogenesis and oogenesis

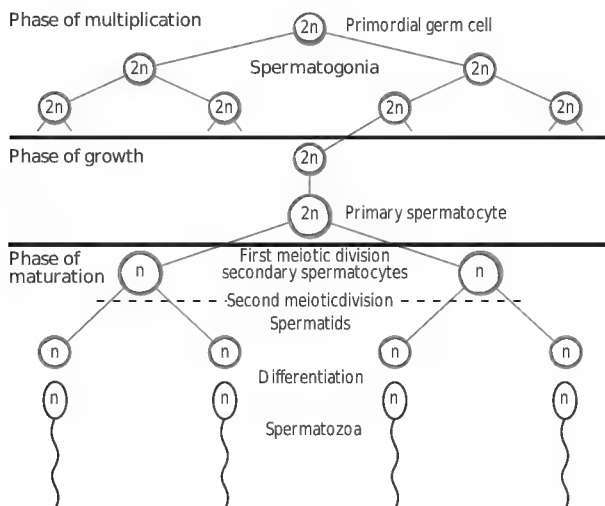
Spermatogenesis is the term used to describe the production of male gametes (sperm). Oogenesis is the production of female gametes (ova). These two processes share many essential similarities, such as the central role of meiosis in creating haploid gametes. There are however several differences in the timing and organisation of the processes. These can help to explain why adult males produce several million small sperm per day whilst women produce just one large, mature ovum (secondary oocyte or 'egg' cell) per month.

Spermatogenesis

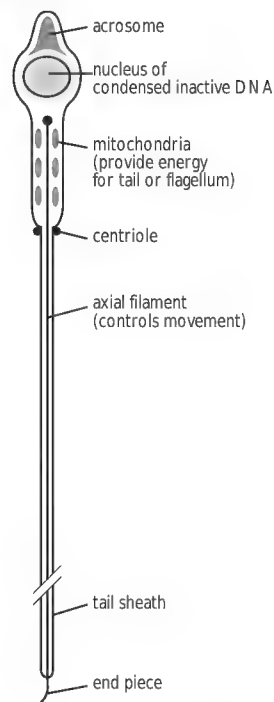
Sperm are produced in the seminiferous tubules within the testes of the adult male. The process of spermatogenesis is initiated by the hormone testosterone at the time of puberty. Epithelial germ cells in the outer layer of the seminiferous tubule divide by mitosis to form a population of diploid **spermatogonia**. These divide by mitosis and grow into **primary spermatocytes**. Each primary spermatocyte undergoes meiosis, forming two haploid **secondary spermatocytes** in Meiosis I and four **spermatids** in Meiosis II. In the final stage each spermatid develops from a round cell into a fully functional sperm cell (**spermatozoa**). This complete process of spermatogenesis takes about 70 days.

As spermatogenesis progresses, the developing sperm cells move towards the lumen of the seminiferous tubule into which they will eventually be released. The cells are attached to large **Sertoli cells** (nurse cells) until maturity. These cells provide oxygen and nutrients and remove waste products. They also play an essential role in remodelling the spermatid to form a sperm cell.

A mature sperm is approximately 20 μm in length and 2.5 μm in diameter, the smallest cell in the human body. It consists of a **head**, containing a haploid nucleus and a membrane bound sac of enzymes at the tip, (the **acrosome**), a **middle piece** containing many mitochondria to provide energy for swimming, and a tail containing microtubules.



Spermatozoon



Oogenesis

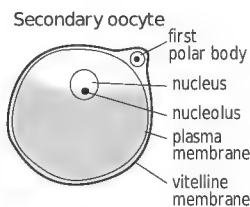
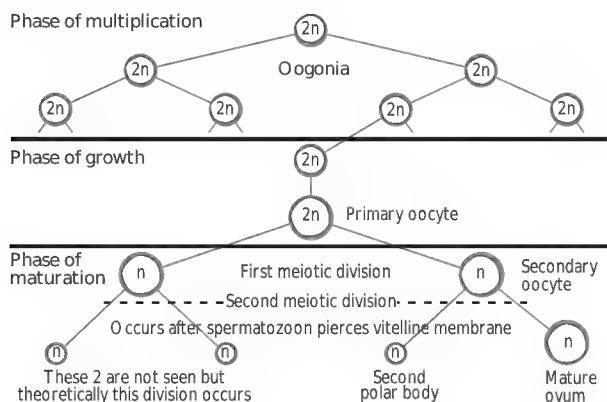
Unlike spermatogenesis, oogenesis does not begin at puberty, but in fetal life. Oogenesis begins in the germinal epithelium of the ovary where germ cells divide by mitosis to form **oogonia**. Further mitosis and growth of these cells produces **primary oocytes**. These cells begin Meiosis I but are halted during prophase. A layer of granular cells develops around each primary oocyte forming a **primary follicle**. Several million of these follicles are present at birth of which only a fraction will complete their development into gametes during the reproductive life span of the woman. From puberty onwards one follicle per month will complete its development into an **ovarian follicle** (Graafian follicle) containing a mature female gamete. The stages in the development of one follicle and the primary oocyte within it can be summarised as follows:

The primary oocyte inside the follicle enlarges whilst its surrounding granular cells increase in number, and are surrounded by an outer layer of cells (the **theca**) derived from the tissue of the ovary. Under the influence of **follicle stimulating hormone** (FSH) and **luteinising hormone** (LH) the follicle continues to grow into a secondary follicle, developing a central space filled with fluid secreted by the granular cells. Further enlargement, under the influence of oestrogen secreted by the granular cells, produces a mature Graafian follicle up to 1cm in diameter.

Meanwhile, inside the follicle the primary oocyte completes its first meiotic division, forming a haploid **secondary oocyte** and a small functionless **polar body** (containing the other half of the chromosomes). The second meiotic division begins but is halted in metaphase. At this point, mid way through the menstrual cycle, the Graafian follicle bursts to release the secondary oocyte. Meiosis II is not completed until the moment of fertilisation when a second polar body is formed. Strictly speaking the term **ovum** should not be used until that point.

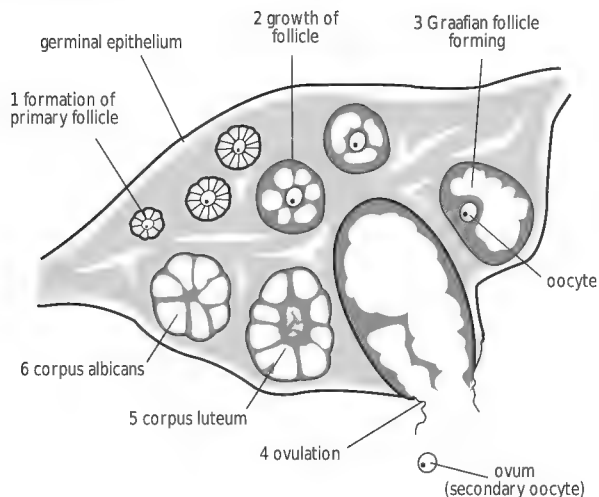
The secondary oocyte which is released at ovulation is a large cell, about 140 μm in diameter. It contains a haploid nucleus and a large quantity of grainy cytoplasm. It is surrounded by a jelly like layer, the **zona pellucida**. The ovarian (Graafian) follicle after releasing the secondary oocyte becomes the **corpus luteum** which has an important role in the secretion of progesterone and oestrogen.

All of the changes described above occur during a single menstrual cycle. Further details of the menstrual cycle are given below.



Polar bodies take no part in reproduction and disappear, therefore only one functional cell is produced from the primary oocyte.

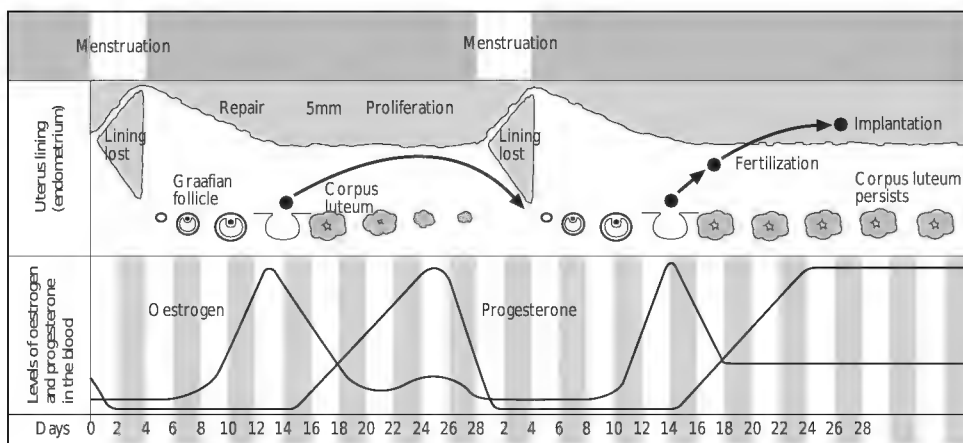
Mammalian ovary section



The menstrual cycle

Between puberty (average age 12) and the menopause (average age 45) human females experience regular sexual cycles, known as menstrual cycles. Each cycle is approximately 28 days long and involves a series of changes within the ovary and uterus. These can be considered as two separate but closely linked cycles: the **ovarian cycle** which is concerned with the development and release of an 'egg cell' around the mid point of the cycle, offering the chance of fertilisation if mating occurs; and the **uterine cycle** which is concerned with the development of the endometrium (uterus lining) to ensure the highest chance of implantation of a fertilised ovum or zygote.

Unless pregnancy occurs, one menstrual cycle will follow directly on from the next. (Therefore when interpreting graphs of the cycle note that day 28 is followed by day 1.)



The events of the menstrual cycle

The menstrual cycle relies on interactions between four main hormones: the ovarian hormones oestrogen and progesterone and the pituitary hormones Follicle Stimulating Hormone (FSH), and Luteinising hormone (LH). A further hormone, from the hypothalamus, Gonadotrophin Releasing Hormone (GnRH) is also involved. The events of the menstrual cycle are summarised below:

- ▼ Release of GnRH from the hypothalamus causes FSH to be released from the anterior pituitary. FSH travels in the bloodstream to the ovaries where it stimulates the development of several follicles (primary oocytes). One or more of these will eventually mature into an ovarian (Graafian) follicle containing the secondary oocyte.
- ▼ FSH stimulates the production of oestrogen from the follicles within the ovaries. This oestrogen in turn stimulates the growth of the endometrium, replacing cells lost during the previous menstrual period. At this point oestrogen has a negative feedback effect on FSH, reducing its production.
- ▼ Oestrogen levels increase until the mid point of the cycle when they bring about a peak of LH production from the anterior pituitary causing ovulation (the release of the secondary oocyte from the Graafian Follicle). A small peak of FSH production also occurs at the time of ovulation.
- ▼ LH causes the Graafian Follicle to develop into a corpus luteum which begins to secrete progesterone and oestrogen.
- ▼ Progesterone stimulates further development of the endometrium, in particular an increase in the density of spiral arteries and an increase in the secretion of mucus and fluid from glands in the endometrium. This is sometimes known as the secretory phase and its function is to prepare the uterus in case the newly released secondary oocyte ('egg' cell) is fertilised.
- ▼ The other function of progesterone is to inhibit the production of both FSH and LH and hence the development of further follicles. This is an example of negative feedback.
- ▼ If fertilisation does not occur, the corpus luteum degenerates and secretion of progesterone and oestrogen falls. This fall causes the uterine blood vessels to rupture and the uterus lining to degenerate and pass out of the body via the vagina. This is known as menstruation or the menstrual period and lasts for 4-5 days. Decline in progesterone levels causes the inhibition of FSH and LH to be removed and a new cycle can begin. Note that a new cycle begins whilst menstruation is still occurring.
- ▼ If fertilisation does occur then the corpus luteum does not degenerate but continues to secrete progesterone and oestrogen, maintaining the uterus lining and preventing further follicles from developing. After about 12 weeks of pregnancy in humans and corresponding times in other mammals the developing placenta takes over this hormonal (endocrine) role.

◆ CHECKPOINT SUMMARY

- ◆ The ova are produced (oogenesis) by meiosis in the germinal epithelium of the ovaries. Of the four products of meiotic nuclear division, one accumulates all the cytoplasm to form the relatively large ovum, and the others are reduced to polar bodies.
- ◆ Spermatozoa are produced (spermatogenesis) by meiosis in the germinal epithelium of the testes. The four products of meiosis all develop into spermatozoa.
- ◆ The menstrual cycle is a monthly version of the ovarian cycle found in all mammals.
- ◆ A sequence of hormonal secretions from the brain, pituitary gland, and the ovaries themselves, coordinated by negative feedback loops control the events of the cycle.
- ◆ Luteinising hormone stimulates the release of the an ovum from an ovarian follicle, and the development of the corpus luteum. In the male it stimulates the secretion of testosterone by the testes.
- ◆ Follicle stimulating hormone initiates the development and growth of the ovarian follicles, and stimulates the ovary to secrete oestrogen. In males it stimulates spermatogenesis in the testes.
- ◆ Oestrogen stimulates the development of the primary and secondary sexual characteristics, the development of the uterus lining in the first half of the menstrual cycle.
- ◆ Progesterone stimulates the secretory phase of the uterus in the second half of the cycle, and maintains pregnancy whilst suppressing further ovulation.

The transfer of male gametes and fertilisation

If fertilisation is to occur then male gametes must come into contact with the female gametes. Under natural circumstances male gametes are transferred into the reproductive tract of the female via the penis during sexual intercourse.

For sexual intercourse to occur, the male's penis must first become erect. This occurs following sexual stimulation and involves an increase of blood flow into the spongy erectile tissue of the penis. Movement of the erect penis inside the vagina during intercourse stimulates the sensory cells at the tip of the penis. A series of stages, co-ordinated by the sympathetic nervous system then follow, eventually leading to ejaculation: the release of semen containing sperm into the vagina. These stages include:

- ▼ contraction of the involuntary muscle lining the sperm duct and epididymis so forcing the sperm towards the urethra;
- ▼ contraction of the seminal vesicles, Cowper's and prostate glands which add their secretions to the sperm;
- ▼ closure of the bladder sphincter muscle; and reflex contractions of the muscles surrounding the urethra, forcing the semen out of the penis and high into the vagina of the female. Ejaculation is accompanied by the intense sensation of orgasm.

A single ejaculation can contain several hundred million sperm. Once in the vagina these sperm acquire the ability to swim and begin their journey through the cervix (first aligning themselves with long chains of mucus), across the uterus and up into the oviducts. The speed with which they may reach the oviducts suggests that muscular movements of the uterus and oviduct may in fact be more important than swimming at this stage. It has been suggested that chemicals called prostaglandins contained in seminal fluid could bring about this effect. If ovulation has occurred within 24 hours prior to this, a secondary oocyte should be present in one of the oviducts and it is here that fertilisation may take place.

Fertilisation

Fertilisation is the process by which the haploid nucleus of a single sperm cell fuses with the haploid nucleus of a single ovum creating a diploid zygote.

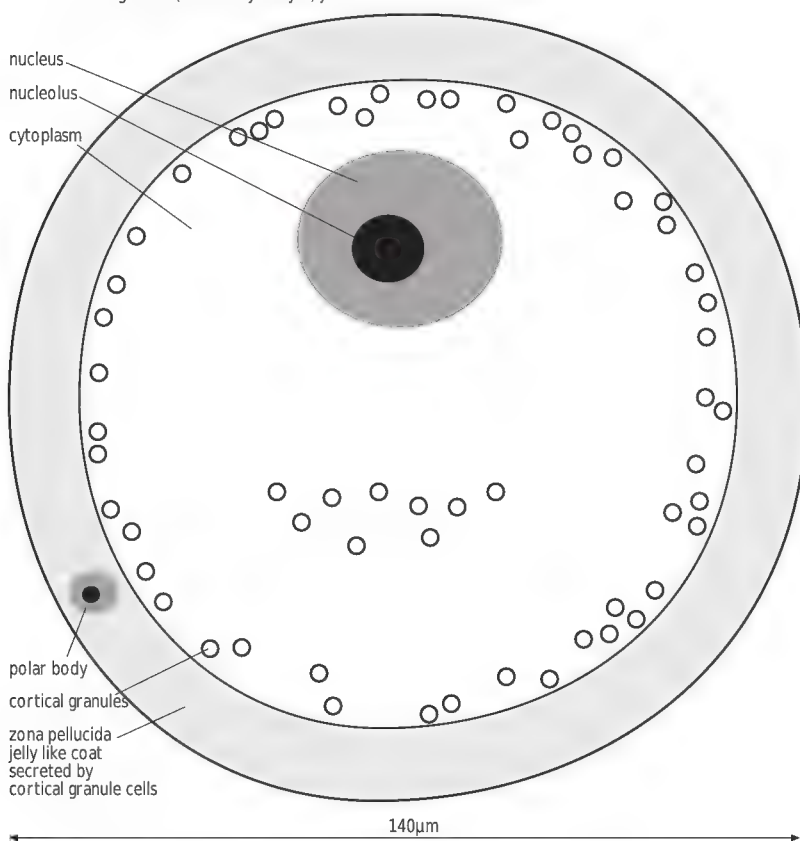
Before a sperm can fertilise the secondary oocyte it must undergo a process known as **capacitation** where it is 'primed' for the process by the acid environment of the uterus. The main feature of this involves changes in the cell membrane of the sperm in the region around the acrosome vesicle. Firstly the membrane is weakened and becomes more permeable, and the acrosome membrane fuses with the cell membrane.

When a sperm comes into contact with the zona pellucida of a secondary oocyte the acrosome reaction occurs. This involves the acrosome splitting open and releasing the lytic enzymes contained within it. These begin to digest the zona pellucida, allowing the sperm to move through it to reach the cell membrane of the secondary oocyte. When it reaches the membrane it fuses with it and its head enters the cytoplasm. The tail is left behind. Entry of the sperm stimulates the nucleus of the secondary oocyte to complete its second meiotic division so that it can fuse with the nucleus of the sperm.

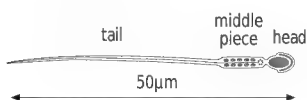
Unit 2H: Exchange, Transport and Reproduction in Humans

One of the surprising things about fertilisation is the mechanism which allows just one single sperm to penetrate the secondary oocyte when several hundred or thousand sperms are surrounding this cell. As the sperm enters the secondary oocyte a number of changes occur which result in the layer surrounding the egg cell (zona pelucida) becoming impermeable to other sperm.

Human female gamete (secondary oocyte) just before fertilisation

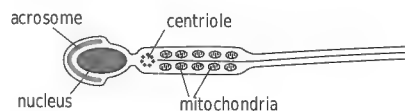


Human male gamete just before fertilisation



140µm is smaller than the smallest dot you can make with a fine ball point pen

Spermatozoon detail



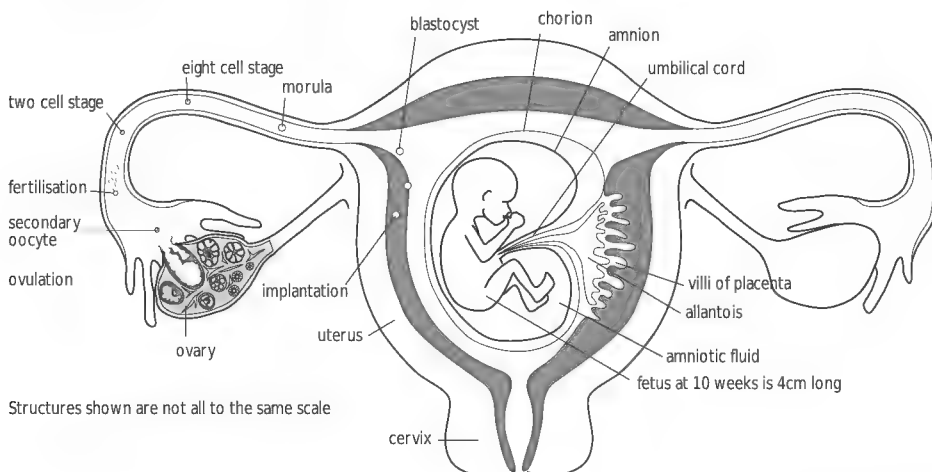
Implantation

Following fertilisation the zygote undergoes cell division by mitosis forming a small ball of identical cells within a few days. Gradually the cells start to differentiate (become specialised for different tasks) and the ball of cells becomes a hollow sphere filled with fluid (blastocyst). The outer wall of the blastocyst is made of cells called **trophoblasts** which will form the villi which grow into the wall of the uterus at implantation. A small mass of cells inside this layer will form the embryo. As these changes occur, the zygote moves slowly down the oviduct and towards the uterus where it must implant in the uterine wall if further development is to take place. The cells secrete a hormone called **human chorionic gonadotrophin (hCG)** which maintains the corpus luteum, ensuring that it continues to secrete oestrogen and progesterone. (The presence of hCG in the urine is detected in a 'pregnancy test'.)

When the blastocyst arrives in the uterus it is still contained within the zona pellucida. As this breaks down the trophoblastic cells of the blastocyst come into contact with the endometrium of the uterus. They begin to invade the endometrium, secreting digestive enzymes and growing into the maternal tissues. This process, which results in the blastocyst becoming embedded in the endometrium, is known as implantation. It occurs as early as seven days after fertilisation.

Implantation is the first stage in the crucial association between maternal and fetal tissues and circulation which form the basis of mammalian development. As the trophoblastic cells become embedded in the endometrium of the uterus they differentiate to form finger like projections which penetrate deep into the endometrium. These are the **chorionic villi**. Enzymes secreted by the cells of the villi digest the walls of the spiral arteries and veins within the endometrium and create blood filled spaces around each villus. From here the maternal blood nutrients and oxygen diffuse into the villi and are delivered to the cells of the blastocyst. Carbon dioxide and other waste materials diffuse out of the blastocyst and into the maternal blood down their concentration gradients. The efficiency of these exchanges is improved by the large surface area of chorionic villi.

Over the following weeks rapid growth and development of both the chorionic region and the embryo occur. Within three to four weeks of fertilisation blood is circulating through embryo and villi. This improves the efficiency of exchange.



The structure and function of the placenta

The placenta is fully formed 12 weeks after fertilisation. On the maternal side it consists of projections of the endometrium between which lie a series of blood filled spaces. Blood from the maternal arteries enters the spaces where exchange is performed and then returns to the circulation in the maternal veins. On the fetal side, chorionic villi project into the blood filled spaces. Each villus contains branches of the umbilical artery and vein which form a dense network of capillaries. These join up to form the **umbilical artery** and **veins** which run through the umbilical cord to the embryo (at this stage called the fetus). It should be noted that the blood of mother and fetus are kept entirely separate. This helps to regulate exchanges between mother and fetus, protects the fetus from the effects of high maternal blood pressure which would damage its small blood vessels, prevents possible immune reactions which might occur if the fetus was of different blood group to the mother, and prevents the entry of mature female hormones which would be dangerous even for a female fetus.

The placenta has two main roles in relation to the development of the human embryo and fetus. Firstly it is the organ of exchange between mother and fetus, supplying the fetus with nutrients and oxygen and removing carbon dioxide and urea. Antibodies are also supplied to the fetus which protect it from infections in the first months of life. Secondly it is an endocrine organ producing several hormones throughout the gestation period (development time before birth).

In order to perform its exchange roles efficiently the placenta must provide a large surface area for exchange of nutrients and gases; a thin yet selectively permeable barrier between maternal and fetal blood; and a steep concentration gradient for each substance in the appropriate direction.

A large surface area is provided by the numerous villi and the highly branched capillaries within the villi between the fetal blood contained in vessels and the maternal blood in the large blood filled spaces of the placenta. Maternal and fetal blood are separated by just a few layers of cells creating a short diffusion distance. Small molecules (eg. oxygen, carbon dioxide, urea, water) move across by simple diffusion whilst amino acids and glucose cross by facilitated diffusion. Some vitamins and minerals move by active transport.

Oxygen, glucose, amino acids and other substances required by the fetus need to be at a much higher concentration in the maternal blood than they are in the fetal blood for efficient diffusion to occur. Similarly, carbon dioxide and urea must be at a low concentration in the maternal blood if they are to diffuse out of the fetal blood and be removed. Favourable gradients are maintained by the fact that the fetus has a small volume of blood but a high rate of blood flow whilst the mother has a slower rate of blood flow but a larger volume of blood in the spaces of the placenta, and by an overall counter-current system of blood flow in which the maternal and fetal blood flow in opposite directions maintaining steeper diffusion gradients. Just before birth about 10% of the mother's blood flows through the placenta on each circuit of the body, aiding rapid exchanges.

Harmful substances and the placenta

Since the placenta allows many small substances to cross it by simple diffusion, harmful substances as well as useful ones may easily enter the body of the fetus. Harmful substances can be broadly divided into drugs and chemicals, and pathogenic organisms mainly viruses. Substances in both categories can cause temporary or permanent harm to a fetus, or, in extreme cases lead to death in the uterus.

Most drugs, including nicotine from tobacco smoke, alcohol, heroin, other illegal drugs and pharmaceutical products are very small molecules which will readily cross the placenta from maternal to fetal blood. Since both smoking and drinking are common habits amongst women in most western societies transfers of these harmful substances will be the most significant in terms of numbers of babies affected. Nicotine from tobacco smoke (including passive smoking) leads to reduced growth of the fetus and hence a reduced birth weight; an increased risk of premature birth and an increased risk of fetal death.

Alcohol can also reduce birth weight and if in excess (more than 5 units per day) can lead to fetal alcohol syndrome, characterised by a range of permanent mental and physical defects. The effects of alcohol are most severe during early pregnancy when fetal brain growth is occurring. Use of heroin and cocaine during pregnancy can lead to the fetus becoming addicted and suffering withdrawal symptoms after birth. Permanent brain or organ damage may also result and there is increased risk of death of the baby before and after birth.

Most bacteria and other pathogens are too large to cross the placenta, but a number of viruses may do so. Viruses cannot cross when contained inside cells, but only when infected cells have burst, releasing new viruses into the blood stream. If a mother is infected with Rubella (German measles) during the early stages of pregnancy, when fetal brain and organ development are occurring, severe malformations and mental retardation of the fetus can result. Blindness and deafness are particularly common. The potential seriousness of this virus explains why all girls in Britain are vaccinated against Rubella as teenagers. The Human Immunodeficiency virus (HIV), particularly the form known as HIV2, is also capable of crossing the placenta, although for unknown reasons does so in less than half of infected mothers. There is no cure for HIV, so babies born with the virus will die at a young age.

Hormones secreted by the placenta

The placenta secretes the following main hormones:

- ▼ Human chorionic gonadotrophin (hCG)
- ▼ Progesterone
- ▼ Oestrogen.

Each has specific roles relating to fetal development and/or maternal changes associated with pregnancy, birth and lactation (milk production).

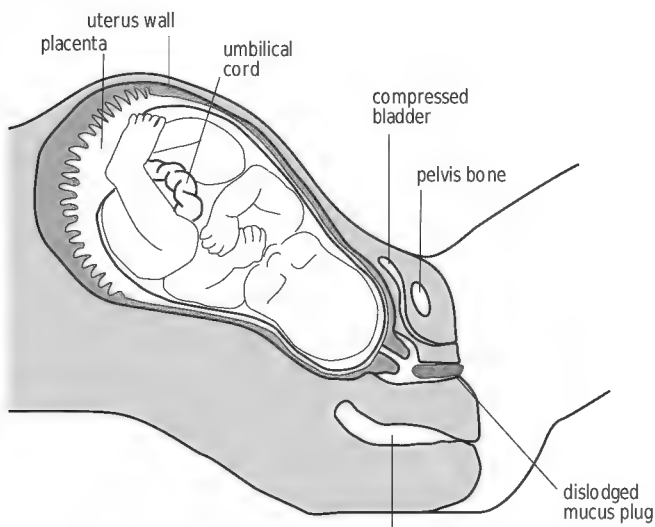
hCG is secreted in only small amounts by the placenta but is thought to have roles in suppressing FSH and LH from the pituitary and in stimulating development of some fetal systems.

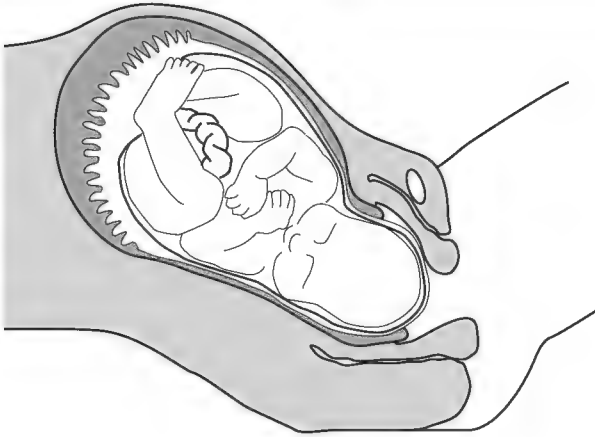
Progesterone is secreted in relatively large quantities (250-350mg/day). High levels prevent shedding of the endometrium, inhibit ovulation and may aid breast development.

Oestrogen is necessary for the maintenance of pregnancy (perhaps through inhibiting FSH) and is thought to be involved in preparing the body for birth and in breast development.

Birth

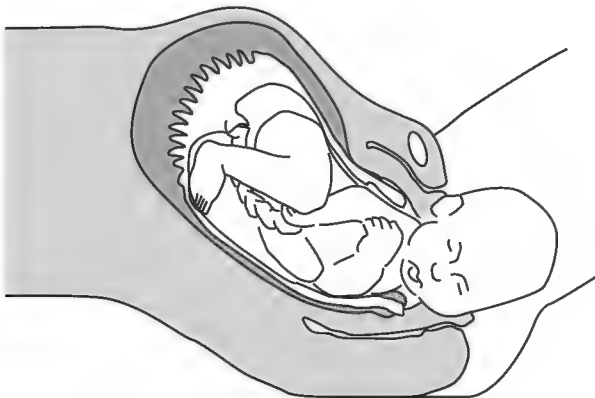
Approximately 38 weeks after fertilisation the fetus is ready to be born. At around this time the level of the hormone progesterone decreases rapidly and the level of oestrogen increases. The effect of this is to make the uterus wall more susceptible to the effects of **oxytocin**, a hormone produced by the posterior pituitary gland, which causes contraction of the muscle layer of the uterus (the myometrium). The exact signals which trigger these changes in hormone levels and hence initiate the birth process are not clear but are thought to involve a mixture of physical and hormonal signals from both mother and fetus.





The birth process can be divided into several stages.

In the **first stage**, which may last 12 hours or more, the uterus begins to contract and the cervix begins to dilate. During, or sometimes before the main contractions begin the amniotic sac bursts and the fluid is released via the vagina. A plug of mucus which blocks the cervix during pregnancy also detaches and passes out of the vagina. Over time the force and frequency of the contractions increases under the control of oxytocin and they spread out through the muscle fibres of the uterus from top to bottom, gradually pushing the fetus downwards toward the cervix. By the end of this stage the cervix has dilated to about 10cm in diameter, wide enough to allow the fetal head to 'engage' and then pass through.



The **second stage** involves the actual birth of the baby which is pushed out of the uterus, through the cervix and down the vagina. The majority of babies are born head first, having moved into this position in the uterus in the weeks leading up to birth. The head and shoulders of the baby are the widest part so once these have passed through the cervix the rest of the body, still attached to the placenta via the umbilical cord, follows more easily. Once it emerges the baby begins to breathe. Since it no longer requires an oxygen supply via the placenta the umbilical cord is cut and tied/clipped.



The **third stage** involves the loss of the placenta from the body. Final contractions about 5 minutes after birth allow the placenta to detach itself from the uterus wall and pass out of the vagina. Although a large loss of blood may be expected, muscle fibres around the blood vessels contract to limit this.

Lactation

In its first nine months of life before birth the fetus obtains all its nutritional requirements via the placenta. After birth it must ingest milk produced by the mammary glands of the mother and delivered via the nipple. Suckling begins soon after birth and a new born baby may spend several hours per day engaged in feeding. For the first four months of life babies are rarely given any other food or drink, and in many cultures breast feeding may continue to supplement other foods for several years. The production of milk is known as lactation.

Milk, is a watery fluid containing the sugar lactose along with fat, and proteins, some vitamins and minerals. It is produced in the milk glands of the breast and its secretion is stimulated by suckling. The substances contained in milk are easily digested in and absorbed from the baby's gut.

Milk production is controlled by the interaction of several hormones. During pregnancy, the hormones oestrogen and progesterone stimulate the development of breast tissue containing milk glands and milk ducts. However, milk is not produced and released at this stage as progesterone and oestrogen inhibit another hormone, **prolactin** which is also required. The fall in levels of progesterone

and oestrogen after birth removes this inhibition and allows prolactin from the anterior pituitary gland to act on the breast tissue. It stimulates the milk glands of the breast which are lined with milk producing epithelial cells to secrete milk.

Milk is not released until the milk ejection reflex is initiated by the sucking action of a baby. The following steps are involved:

- ▼ nerve impulses from sensory receptors in the nipple are sent to the hypothalamus; this stimulates the posterior pituitary gland to produce **oxytocin**;
- ▼ oxytocin acts on the involuntary muscle around the milk glands which contract, forcing milk through the ducts and out of the nipple.
- ▼ At the same time, suckling also causes the release of prolactin from the anterior pituitary, hence maintaining milk production.

By these feedback mechanisms it can be seen that continued milk production and release will only continue if a baby is suckling.

Colostrum and milk production (lactation)

The first secretion from the mammary glands is not, in fact, milk, but a substance known as **colostrum**. This yellowish secretion contains low levels of fat but high levels of protein, including maternal antibodies. This is an important means of providing the new born baby with some immunity to disease and adds to antibodies which may have been delivered from the mother's blood via the placenta.

Subsequently, milk, a watery fluid containing the sugar lactose along with fat, and proteins is produced in the milk glands and secreted during suckling. The substances contained in milk are easily digested in and absorbed from the baby's gut.

The control of milk production (lactation) has been described above.

Continued milk production and release will only continue if a baby is suckling. This explains can explain why a mother's milk supply may 'dry up' if she does not feed her baby for a few weeks, and why some mothers may continue to breast feed for several years.

◆ CHECKPOINT SUMMARY

- ◆ Spermatozoa are ejaculated by the erect penis in the region of the cervix at the entry to the uterus.
- ◆ Peristaltic movements of the female tract and the motility of the spermatozoa themselves result in movement up the oviducts.
- ◆ If these events coincide with the release of one or more ova, fertilisation can occur high up in the oviduct.
- ◆ The fertilised egg immediately enters into mitotic cell division, and is a hollow ball of cells (blastocyst) by the time the uterus is reached.
- ◆ The blastocyst becomes implanted in the pre-prepared lining of the uterus, and secretes gonadotrophic hormone.
- ◆ The lining of the uterus is maintained and the menstrual cycle is suspended.
- ◆ The true placenta develops and secretes progesterone which helps to maintain the pregnancy and suppress further ovulation.
- ◆ The placenta attaches the fetus to the uterine wall and has a large surface area for the exchange of materials with the maternal circulation, e.g the absorption of oxygen and nutrients, and the elimination of waste products, e.g. urea and carbon dioxide.
- ◆ The efficiency of exchanges is increased by extensive breakdown of tissue in the placenta and the uterus wall, reducing the diffusion distance between the two circulations.
- ◆ At full term the fluid filled amnion which surrounds the fetus bursts, the fluid lubricates the system and birth is initiated.
- ◆ The hormone oxytocin secreted by the posterior pituitary lobe produces powerful contractions of the uterus, induces lactation, and stimulates the ejection of milk during suckling.
- ◆ The hormone prolactin secreted by the anterior pituitary lobe stimulates lactation.

Human Growth and development

Growth and development of an individual includes an increase in the number of cells present, an increase in the size of the cells and changes in the functions of cells (cell differentiation). From conception to death some cell populations continue to grow, but the main period of growth for the body as a whole (think of growth in length/height rather than weight) occurs from fertilisation to the end of puberty at about 18 years.

Growth, particularly in height is an important indicator of health and nutritional status of children. Although each child has his or her own genetic potential in terms of body size, all should follow the same pattern of growth. Obvious deviations from a normal pattern can indicate disease.

Normal growth patterns are represented on graphs known as **growth curves**.

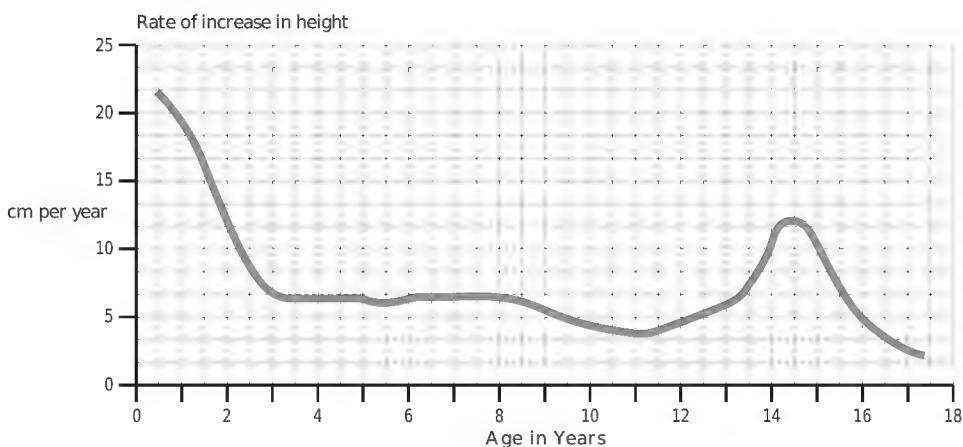
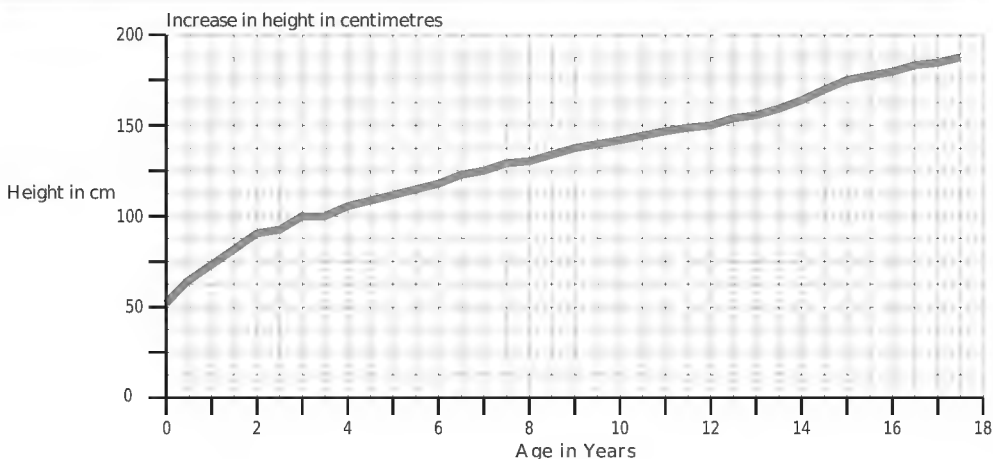
Although the most rapid periods of human growth occur prior to birth, human growth curves, usually begin at birth (0 years) when growth can be most easily measured. The most famous of such graphs are based on the observations of a single child (the son of count Montbeillard, a French nobleman in the 18th century) who was measured twice a year from birth to 18 years. Similar curves can also be made using population data (gathering information of height and weight of a group of individuals at each age).

There are two main types of growth curves that can be plotted using such data:

▼ **Actual or absolute growth curves** will show age in years on the X axis and height or weight on the Y axis. Clearly as age increases height and weight increase, showing a positive correlation. The slope of the line may vary at different ages, being steeper in the first year and around puberty than at other times. The steeper the line at any particular point, the faster the rate of increase.

▼ **Growth rate curves** with years of age on the X axis and velocity of growth (cm per year or kg per year) on the Y axis give much more information as to the rate of growth throughout life. These reveal enormous variations (up to 5-fold) in growth rate (height) over the course of the growth period.

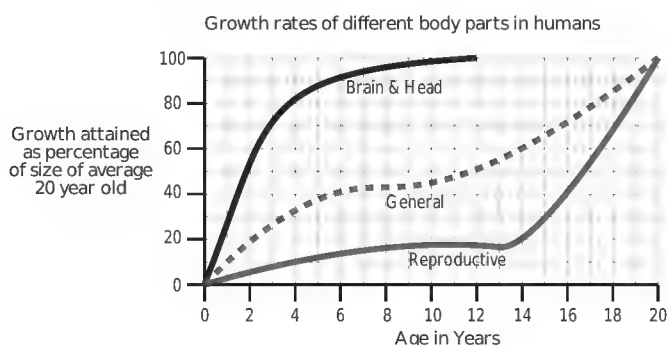
In considering curves of post-natal growth the growth period may be divided into three main stages: infancy (birth to 3 years); childhood (3 -12 years) and adolescence (12-18 years).



It can be seen that growth is most rapid in the infancy period, especially during the first year of life. During this first year weight may increase by around 200% and length by 50%. After this period the growth rate falls rapidly. Throughout the childhood period the rate of growth continues to fall and then stabilises. Growth in height occurs at a rate of about 5cm a year, a rate that is remarkably constant across populations. An **adolescent growth spurt** begins at the age of 10-14 and lasts for 2-3 years (the age and timing varies with a number of factors and is earlier in girls than boys). Although the rate of growth here is more than double that in the childhood period it is still only half that seen in the first year of life. Following adolescence growth in height declines to zero in adulthood.

Unit 2H: Exchange, Transport and Reproduction in Humans

More detailed graphs can be made to show the growth of individual parts of the body over the period between 0-18 years. Striking differences in body proportions occur over this time as well as the more familiar increases in height and body mass. One of the most significant changes is in the proportion of the head compared to the body. At birth, the head accounts for 25% (1/4) of body length, whereas it accounts for only 12.5% (1/8) of body length of an adult. The head/brain achieves its adult size by the age of about 12 years, whilst the body as a whole continues to grow for about 18 years. Most organs follow the growth pattern of the body as a whole, but the reproductive organs are small until the onset of puberty and then grow rapidly. Body composition in terms of fat and muscle cells also changes over the first 18 years of life, with males developing relatively more muscle tissue and females relatively more fat tissue (25%) than males (12.5%).



The effects of ageing

As the life expectancy of humans continues to increase, the effects of ageing (senescence) are becoming common sights and common medical problems. All systems of the body deteriorate gradually with age including the brain and nervous system, the skeletal system, the respiratory system, the circulatory system, and the reproductive system. The rate of deterioration of systems is highly variable between people and undoubtedly has both genetic and environmental causes.

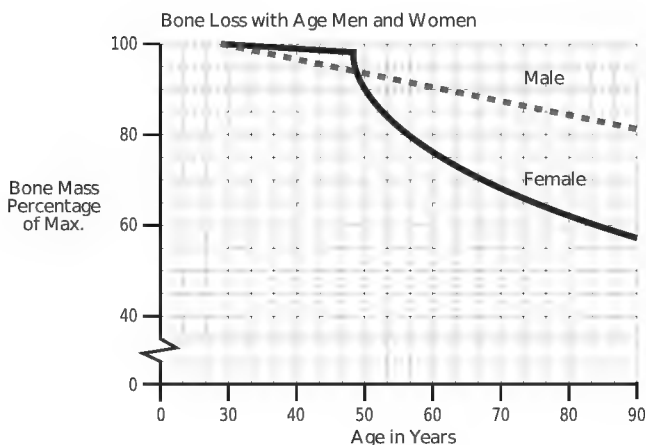
The skeletal system

Osteoarthritis is a very common degenerative condition which causes pain and stiffness and loss of movement in the large weight bearing joints of the body such as the hips and knees and back. The symptoms, which can be very severe, result from the gradual loss of cartilage from the surfaces of the joints (articular cartilage).

Joints which are designed to allow movement (synovial joints) have a layer of cartilage up to 3mm thick covering the surface of each bone. This acts as a shock absorber and allows the bones to move smoothly over each other. In osteoarthritis this layer becomes

fragmented or completely worn away, allowing the bones to rub directly against one another. This causes pain as there are many nerve endings in the bone. Destruction of the cartilage also stimulates the production of new bone at the joint surface. This strengthens the bone but can lead to deformities to the bone which in turn reduce movement of the joint. This is often seen in the bones of the fingers which become swollen and bent. Biochemical changes within the remaining cartilage also occur, making it less elastic and reducing its shock absorbing capacity.

Osteoporosis, a condition involving a loss of bone mass and increased risk of bone fracture, is a feature of ageing which affects all older people to some extent, but is particularly severe in elderly women. From the age of thirty onwards, bone mass may be lost at a rate of 0.5-1% per year, accelerating to up to 3% per year in women after the menopause. The bones gradually become thinner and weaker as calcium is lost from bones more rapidly than it can be replaced.



Sufferers of osteoporosis have bones with a spongy appearance which are brittle and break easily. Bones most affected include the wrists and hip bones which are often fractured through falls. The vertebrae (back bones) are also affected. These become compressed leading to a loss of height, and may collapse, becoming misaligned and leading to curvature of the spine. Treatment includes supplementing the diet with calcium, fluoride or vitamin D (required for calcium uptake). In post menopausal women hormone replacement therapy (mainly using oestrogen) also has a protective effect.

Cardiovascular system

Age above 40 years is a risk factor for all cardiovascular conditions (conditions relating to the functioning of the heart and blood vessels). This includes **atherosclerosis**, a condition in which the arteries become hardened and slightly narrowed by the deposition of fatty deposits (atheromata or plaques) in the wall of the artery. This condition can lead to **angina** and **coronary heart disease** (CHD) and can increase the risk of **stroke** (through thrombosis or blood clots), two of the most important causes of death in Britain today. Atherosclerosis also contributes towards a reduced cardiac output, and increased blood pressure which can limit activity in later life.

As with other degenerative conditions, atherosclerosis does not happen suddenly, but rather as a result of many years or decades of subtle changes in the artery wall. There are many risk factors such as smoking, consumption of a high fat diet, lack of exercise, which increase the chance of individuals developing the disease. An older person will have had more years of exposure to any risk factors.

Prior to the menopause the risk of atherosclerosis and CHD is much greater in men than women, yet in post menopausal women the rates are the same. The effect seems to be related to oestrogen levels. High levels of oestrogen are thought to reduce the levels of harmful low density lipoproteins (fat molecules associated with protein) in the body and increase the levels of beneficial high density lipoproteins. The ratio is reversed when oestrogen levels fall after the menopause.

Reproductive systems

Men remain biologically capable of fathering children throughout their lifetime (there are many examples of men aged 80 or more becoming fathers) since sperm continue to be produced constantly. In contrast, women are only fertile for around 30-35 years of their life. Timings are very variable, but menstrual cycles usually begin between the ages of 11 and 15 and continue until the age of 45-50 years. At around this time women enter the **menopause**, a period of months or years during which the activity of the reproductive system declines. The most obvious manifestation of this is that menstrual cycles become infrequent and then stop.

At the onset of the menopause, follicles in the ovaries stop responding to the pituitary hormones FSH and LH, ovulation does not occur and pregnancy is therefore not possible. Another effect of the failure to respond to FSH and LH is that the ovaries stop producing the hormones oestrogen and progesterone. Low levels of oestrogen seem to have particularly marked effects on women's health. This can bring about hot flushes (linked to high FSH and LH levels) and a range of psychological symptoms including anxiety and forgetfulness. Other common problems include reduced elasticity and thinning of the vaginal membranes which may reduce the enjoyment of sex. In addition, as mentioned elsewhere, the fall of oestrogen levels increases the risk of both osteoporosis and coronary heart disease.

It should perhaps be noted that whilst men may still retain their fertility until late in life some changes do occur. Impotence (inability to maintain an erection) is a common problem in older men, limiting sexual activity.

Hormone replacement therapy

It is possible to treat some of the psychological and physiological effects of the menopause with hormone replacement therapy (HRT). This involves female hormones, especially oestrogen, taken in the form of pills or in an implant device beneath the skin. In addition to treating the short term effects of the menopause (e.g psychological symptoms and hot flushes which normally last for only a short time), long term use of HRT can reduce the risk of severe osteoporosis and cardiovascular disease as mentioned above. It should be noted, however, that the HRT treatment given to menopausal women does not cause menstrual cycles to continue, nor does it restore fertility.

◆ CHECKPOINT SUMMARY

- ◆ Although the most rapid periods of human growth occur prior to birth, human growth curves, usually begin at birth (0 years).
- ◆ Growth curves are steeper in the first year and around puberty than at other times: infancy (birth to 3 years); childhood (3 -12 years) and adolescence (12-18 years).
- ◆ The effects of ageing (senescence) are becoming common sights and common medical problems. All systems of the body deteriorate gradually with age including the brain and nervous system, the skeletal system, the respiratory system, the circulatory system, and the reproductive system.
- ◆ Osteoarthritis is a very common degenerative condition which causes pain and stiffness and loss of movement in the large weight bearing joints of the body such as the hips and knees and back, as a result of the gradual loss of cartilage from the surfaces of the joints (articular cartilage).
- ◆ Osteoporosis, a condition involving a loss of bone mass and increased risk of bone fracture, is a feature of ageing which affects all older people to some extent, but is particularly severe in elderly women.
- ◆ Age above 40 years is a risk factor for all cardiovascular conditions (conditions relating to the functioning of the heart and blood vessels). This includes atherosclerosis, a condition in which the arteries become hardened and slightly narrowed by the deposition of fatty deposits
- ◆ This condition can lead to angina and coronary heart disease (CHD) and can increase the risk of stroke (through thrombosis or blood clots), two of the most important causes of death in Britain today.
- ◆ Prior to the menopause the risk of atherosclerosis and CHD is much greater in men than women, yet in post menopausal women rates are the same. The effect seems to be related to oestrogen levels.
- ◆ Men remain biologically capable of fathering children throughout their lifetime. In contrast, women are only fertile for around 30-35 years of their life after which they enter the menopause, a period of months or years during which the activity of the reproductive system declines.
- ◆ The menopause can bring about hot flushes (linked to high FSH and LH levels) and a range of psychological symptoms including anxiety and forgetfulness. Other common problems include reduced elasticity and increased risk of both osteoporosis and coronary heart disease.

Biology or Biology (Human)



Unit 3 Energy & the Environment

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Unit 3

Energy and the Environment

Contents

3.1	
Modes of Nutrition	1
▼Autotrophic and heterotrophic nutrition	
▼Holozoic nutrition	
▼Saprobiontic and parasitic modes of nutrition	
▼Mutualistic nutrition	
3.2	
Ecosystems	9
3.3	
Energy Flow	11
3.4	
Recycling of Nutrients	15
3.5	
Energy Resources	21
3.6	
Human Influences on the Environment	23

3.1

Modes of Nutrition

Content

Autotrophic and heterotrophic nutrition

- ▼ Basic principles

Holozoic nutrition

- ▼ The adaptations of herbivores and carnivores to their diet, as illustrated by a named ruminant and a named carnivore.

Saprobiontic and parasitic nutrition

- ▼ Illustrated by *Rhizopus* and *Taenia*.

Mutualistic nutrition

- ▼ Illustrated by *Rhizobium* with Papilionaceae and cellulose-digesting organisms in ruminants.

AUTOTROPHIC AND HETEROTROPHIC NUTRITION

Autotrophic means 'self feeding' and it is a term applied to the nutrition of those organisms which obtain energy directly from their surroundings, taking in simple inorganic substances such as carbon dioxide, water and inorganic ions to build up complex molecules. The most important energy source for autotrophic nutrition is the sun and the most important process is **photosynthesis** by which green plants convert the sun's energy into a food resource used by all other organisms. An alternative energy source is exploited by **chemosynthetic** bacteria which use the energy produced by chemical reactions to make food. Nitrifying bacteria, for example (ref 3.4) are able to use the energy released from the oxidation of ammonium and nitrite ions to synthesise food materials and in the process release nitrates which enrich the soil.

Heterotrophic means 'other feeding' and it is applied to all organisms which obtain their energy by breaking down (digesting) materials from the bodies of other organisms. The products of digestion are simple organic molecules such as glucose and amino acids which, with inorganic ions, can be built up into more complex materials such as DNA and proteins.

HOLOZOIC NUTRITION

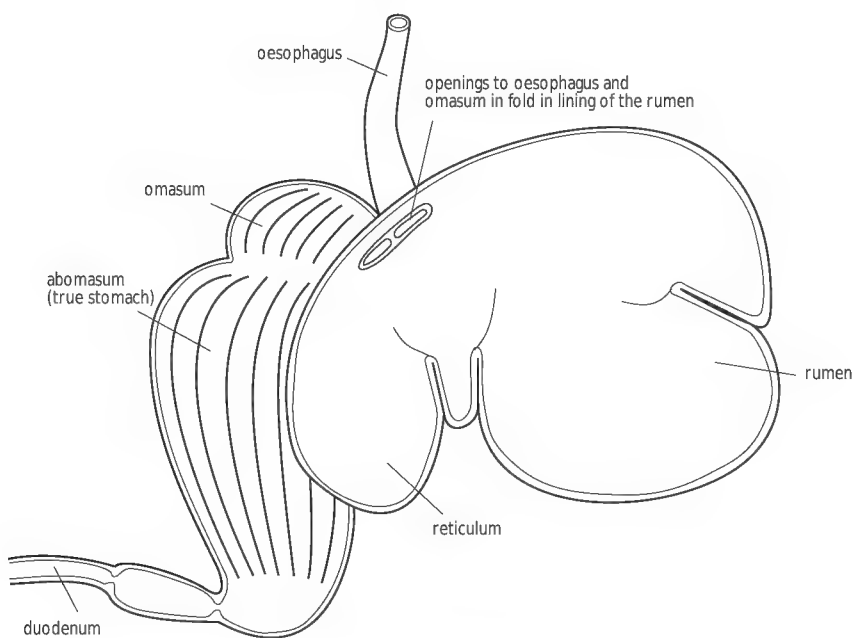
'Zoic' means 'animal like' and the term **holozoic** nutrition refers to those heterotrophs which feed 'like animals', in other words, those which engulf or swallow organic material from plant and animal sources. It includes the **herbivores** (animals which feed on plant material), **carnivores** (animals which feed on animal material), and **omnivores** (animals which obtain their food from both plant and animal sources).

Special adaptations of herbivores and carnivores to their diet

Herbivorous diet

Vegetation is relatively low in nutritional value when compared to meat. Plant cells have cellulose, and sometimes lignified, cell walls, enclosing the contents of the cells, which must be broken down before the contents can be released for digestion. Therefore vegetation requires much mastication (chewing), especially grasses, as their epidermal cell walls are hardened with silica. Therefore herbivores have many adaptations for the mastication and digestion of large volumes of plant material. Vertebrates do not produce their own cellulase enzymes, but harbour huge numbers of mutualistic microorganisms (bacteria and protoctists) which secrete cellulase enzymes. Herbivores therefore have a long complex gut in proportion to their body size, when compared to carnivores.

The complex nature of digestion and absorption in herbivores is illustrated in the **ruminants**. These include the 'cloven-hoofed' mammals such as the goats, deer, cattle and sheep.



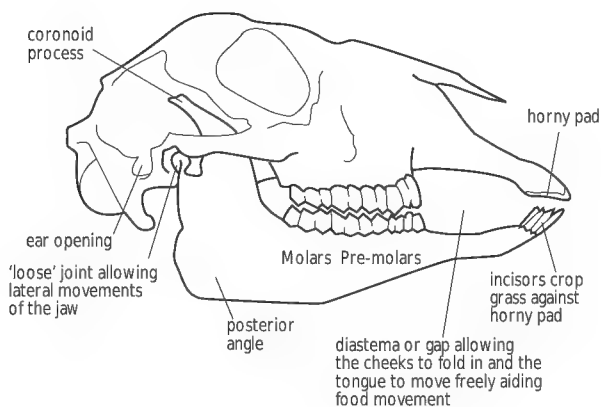
They have an elaboration of the oesophagus and the stomach into four chambers. The food is cropped and swallowed without chewing with a large volume of saliva into the chamber known as the **rumen**. The rumen contains vast quantities of mutualistic bacteria. The bacteria convert the cellulose into fatty acids which, along with lactic and other organic acids produced by anaerobic fermentation, are absorbed into the bloodstream. Large volumes of carbon dioxide and methane are also produced, and are vented off. Ciliated protoctists feed on the bacteria and are in turn digested as a source of protein. Optimum conditions for

all these activities in the rumen are maintained by the production of large volumes of alkaline saliva. The food then passes into reticulum where it is stored temporarily and formed into small compact balls of cud. These are returned to the mouth where they are masticated in a process known as 'chewing the cud'. The food is then re-swallowed into the third chamber (the omasum) where water is absorbed, and then moves into the true stomach (abomasum) where normal gastric digestion occurs. The contents of the plant cells are liberated by the breakdown of the cell walls by bacterial cellulase and then digested by normal gut enzymes in the true stomach and intestines.

Features of the skull of a herbivore

- ▼ Eye sockets at sides giving all round vision and enabling the animal to spot predators
- ▼ Incisors have a flat cutting edge and are often absent on the upper jaw (replaced by a horny pad against which vegetation is torn off)
- ▼ Canine teeth absent leaving gap (diastema) through which tongue can manipulate vegetation
- ▼ Cheek teeth (premolars and molars) are very large and have a ridged surface for grinding
- ▼ Loose jaw articulation for lateral grinding movements

Whilst carnivores hunt and kill at intervals; herbivores with their requirement for large volumes of vegetation, spend much of their time feeding.

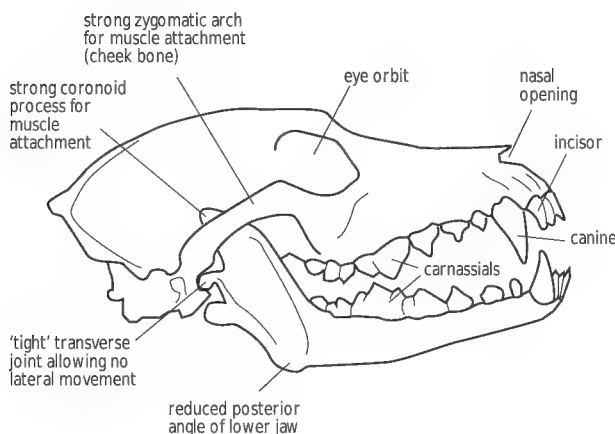


Carnivorous diet

The carnivorous diet is mainly protein but is rich in all the necessary nutrients, and as animal cells (in meat) do not have a cellulose cell wall meat is relatively easy to digest compared to plant material. Also relatively smaller volumes have to be eaten by carnivores compared to herbivores. However, the prey must be caught (unless dead animals are scavenged) and the skull, jaws and dentition of predators are modified for cutting and tearing rather than for chewing.

Features of the skull of a carnivore

- ▼ Eye sockets face forwards giving binocular 3-D vision which allows the animal to judge distance when hunting.
- ▼ Incisors sharp and pointed for gripping prey
- ▼ Powerful canine teeth for gripping and tearing
- ▼ Cheek teeth adapted to sharp shearing carnassials
- ▼ Tight jaw articulation for scissor-like action of carnassials
- ▼ Central ridge on top of the skull for the attachment of muscles which power the biting action of the jaws
- ▼ Strong cheek bone (zygomatic arch) for strong muscle attachment



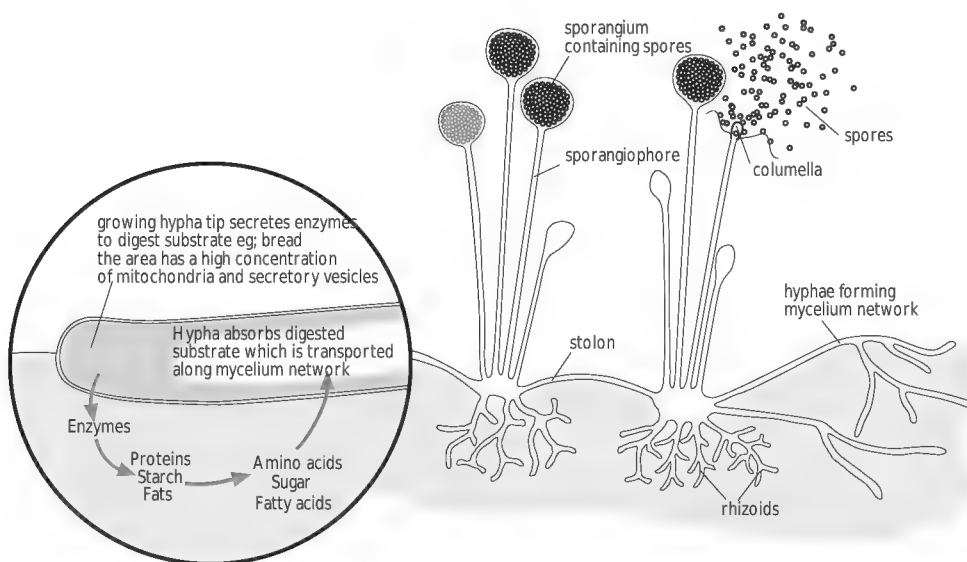
◆ CHECKPOINT SUMMARY

- ◆ Autotrophic nutrition is that in which the organism is capable of synthesising its organic substances from simple inorganic substances using an external energy supply
- ◆ In chemosynthesis the energy supply is derived from energy releasing (exothermic) inorganic chemical reactions, e.g. the oxidation of ammonium ions to nitrites by *Nitrosomonas* bacteria in the soil; and the oxidation of nitrite ions to nitrate ions by *Nitrobacter* bacteria in the soil. These two bacteria being important in the Nitrogen Cycle
- ◆ In photosynthesis the energy supply is derived from light which is absorbed by the photosynthetic pigments chlorophyll a and b, carotene and xanthophylls
- ◆ Holozoic nutrition means feeding in an 'animal-like' manner by engulfing organic material; e.g. an amoeba engulfing particles with its pseudopodia, and humans swallowing food
- ◆ Heterotrophic nutrition is that in which the organism requires an external source of organic substances, in addition to inorganic substances
- ◆ Herbivores are adapted to a diet of large amounts of difficult to digest plant material which is poor in nutrients
- ◆ They have a specialised grinding dentition, and long guts with mutualistic microorganisms in specialised regions digesting the tough cellulose cell walls of plant material. Ruminants soften plant materials up in specially modified 'stomachs' regurgitate it for rechewing (chewing the cud) before reswallowing
- ◆ Carnivores feed on other animal material which is readily digested and rich in nutrients (especially proteins)
- ◆ They have a sharp piercing and slicing dentition to kill the prey and tear off the muscle, tendons and bones. The food is not chewed, and the gut is relatively short and simple.

SAPROBIONTIC AND PARASITIC NUTRITION

Saprobiontic organisms are heterotrophs which live and feed on dead and decaying organic material. They include many fungi and bacteria and are referred to as **decomposers**, having a vital role in the recycling of nutrients. This mode of nutrition is well illustrated by the mould fungus *Rhizopus* which is commonly seen growing as a hairy covering on bread. The fungal threads (**hyphae**) which make up the body (**mycelium**) of the organism are white; the greyish appearance is caused by thousands of spore cases (**sporangia**) which are on top of 'stalks' growing vertically up from the main fungal mass (**mycelium**).

Rhizopus feeds by secreting digestive enzymes, principally amylase, onto the food material, and absorbing back the products of digestion. This process, called **extracellular digestion** relies on the presence of sufficient moisture, both for the hydrolysis of food, and for the digested products to be dissolved prior to their uptake by the feeding hyphae. The hyphae of the mycelium have a huge surface area to volume ratio which facilitates extracellular digestion and absorption.



Parasitic nutrition

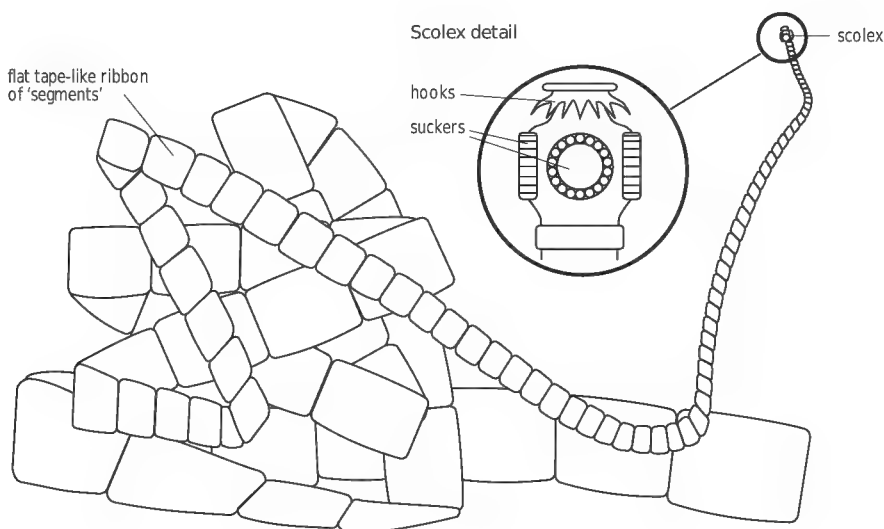
A parasite is an organism which lives on or in, and obtains its food from, the living body of another organism of a different species (the host); to the benefit of itself and the harm of the host. Parasites may feed externally (**ectoparasites**) on plants (e.g. aphids) or animals (e.g. fleas); or they may enter the body to feed internally (**endoparasites**) e.g. *Phytophthora infestans* (the potato blight fungus) and *Taenia* (the tapeworm). The endoparasitic mode of nutrition necessitates various adaptations to body form and physiology which are well illustrated by *Taenia*.

Taenia solium (pork tapeworm) lives in the small intestine of its human host and benefits from a rich and constant supply of ready-digested foods which it simply absorbs across its body surface. Being flattened in form, it has a very large surface area to volume ratio for this purpose. Being in such constant optimum conditions *Taenia* shows a reduction in sense organs, powers of locomotion, and it has no gut of its own.

The small intestine is, however, a very hostile environment for a living parasite. Special adaptations are needed to cope with constant peristaltic movements, a lack of oxygen, and digestive fluids which would break down unprotected animal tissues. *Taenia* is protected by a resistant cuticle over its body surface and attaches to the gut wall by means of hooks and suckers. It respire anaerobically.

Endoparasites have a major problem ensuring that offspring reach new hosts, and this is overcome by huge powers of reproduction, and complex life cycles, often involving more than one host.

Taenia solium has a complex life cycle involving a **secondary host**, the pig, in which its larval stages develop.



MUTUALISTIC NUTRITION

Parasitism is an association between two organisms whereby one, the parasite, gains from the association and the other, the host, is harmed to a greater or lesser degree. A mutualistic association between two organisms is one which benefits both. The two examples described below both involve bacteria, one is a nitrogen source provider with a plant for a partner, the other a cellulose digester in partnership with an animal.

Rhizobium, a nitrogen fixer and the Papilionaceae

The Papilionaceae are a family of pod bearing plants including peas and beans and clover. They have an advantage over other plants because they form mutualistic associations with bacterial colonies of the genus *Rhizobium* capable of 'fixing' atmospheric nitrogen into compounds which can be used by the plant to make protein (ref. 3.4). Freely moving *Rhizobia* enter the relatively unprotected root hair cells of Papilionaceae plants and, once inside, they become enlarged into a form called **bacteroids**. Bacteroids multiply rapidly and affect their host cells in two ways. They cause the cell to produce tiny cellulose tubes called **infection threads** through which they can migrate to the deeper tissues of the root cortex and they secrete chemicals (cytokinins) which induce rapid multiplication of the root cells. The result is a swollen tumour or **root nodule** containing millions of *Rhizobia*.

Rhizobium possesses the enzyme **nitrogenase** which catalyses the conversion of nitrogen gas and hydrogen ions (from bacterial respiration) to ammonia (NH_3). Ammonia can be used directly by the plant, in combination with glutamate to make the amino acid glutamine from which other amino acids can be manufactured. The bacterial cells benefit from the association by having a ready supply of water, and carbohydrates from the plant's photosynthesis, and a degree of protection from competition.

Cellulose digesting organisms in ruminants

These have been referred to above in the account of digestion in ruminants. They are anaerobic bacteria which secrete cellulase enzymes to digest cellulose to glucose, which is absorbed by both the bacteria and the host, or fermented to fatty acids which are in fact the main source of energy for the host ruminant. It is this fermentation that produces the large volumes of carbon dioxide and methane, which on a world scale are significant 'greenhouse' gases. The bacteria can also synthesise amino acids from ammonium ions present in the rumen (urea may be added artificially to the diet of dairy cows to encourage this).

◆ CHECKPOINT SUMMARY

- ◆ Saprobionts (Bacteria and Fungi) physically live on dead or decaying organic matter from which they gain their nutrients. The organism secretes extracellular digestive enzymes onto the organic matter and absorbs the soluble end products of digestion by diffusion. Saprobionts are vital in the recycling of matter e.g. carbon and nitrogen cycles
- ◆ A parasite is an organism that lives on or in another organism of a different species to its own benefit and the harm of the host
- ◆ Thus parasitic nutrition is that carried out by a parasite. Parasites can absorb readily digested material (tapeworm in the gut), bite and feed on blood and fluids of the host (hookworm in the gut), or feed on nutrients in body fluids and cells (malaria parasite in the blood)
- ◆ *Rhizopus* produces a mass of filaments (hyphae) collectively known as a mycelium over and through the dead organic matter. This mycelium has a huge surface area to volume ratio over which it carries out extracellular digestion and absorption of the soluble end products
- ◆ *Taenia* (tapeworm) lives in the gut of vertebrates from which it absorbs the ready digested nutrients. Its long flat tape-like body shape provides a large surface area over which to absorb the nutrients, and has a large surface area to volume ratio for their diffusion to all parts of the body
- ◆ Mutualistic nutrition involves two organisms from different species gaining a mutual benefit in nutrition from their close association
- ◆ *Rhizobium* is a bacterium mutualistic in the root nodules of plants of the Papilionaceae family (legumes e.g. beans, peas, gorse, clover etc.)
- ◆ *Rhizobium* gains organic compounds from the plant, and the plant gains nitrates from *Rhizobium*
- ◆ Microorganisms in the gut of ruminants secrete cellulase enzymes for the digestion of cellulose in the plant material. This liberates the contents for further digestion by the ruminant, and the microorganisms benefit from this.

3.2

Ecosystems

Content

- ▼ Biosphere, ecosystem, habitat.
- ▼ Producers, consumers and decomposers
- ▼ Trophic levels, food chains and food webs.

The Biosphere

The **biosphere** is the name given to that section of the planet which can be inhabited by living organisms. It extends from the upper reaches of the atmosphere to the depths of the oceans, and includes regions as different as the polar ice caps and hot volcanic springs, although these extreme environments can only be exploited by a few specialised life forms. Most organisms require more moderate conditions and exist in mixed communities within defined, and more or less self-contained, sections of the biosphere referred to as **ecosystems**. Terrestrial ecosystems are characterised by a particular type of vegetation, for example, grassland or coniferous forest. Aquatic ecosystems are defined by the type of water: fresh, salty, still or running. An ecosystem consists of three interrelated components: **biotic** (the community of living organisms), **climatic** (temperature, rainfall light etc.) and **edaphic** (soil or water composition).

Each of these components is dependent on the other. In a forest for example, the trees depend on the soil for minerals, but the soil is made stable and fertile in return by the plant roots and decomposing parts of the trees, e.g. leaves. The trees also depend on the climate for light and water, but rain clouds are made up of water vapour, some of which has been transpired from the tree leaves, and large forests have a significant effect on rain fall.

Each living organism has its own **habitat** within the ecosystem. A habitat must provide three essential things which the organism needs to survive. Firstly, it must supply food through all seasons of the year. It must also offer protection from extremes of climate and from other organisms. Finally, it must provide a place to breed, for example, nesting sites and materials for nest building.

For an earthworm or a dandelion all these needs can be supplied by a small area of garden soil. Larger animals require a much greater portion of their ecosystem. Elephants travel many miles to satisfy their needs for food and water, and eagles require large hunting areas with isolated and protected nesting sites. It is small wonder that the creatures with the largest habitat requirements are under the greatest threat from expanding human populations (ref. 3.6).

The term **community** refers to the entire set of organisms which coexist within a particular ecosystem. The total number of individuals of any particular species within that community is termed a **population**, so communities are composed of many different populations. A typical ecosystem such as a pond or forest

consists of populations of producers, consumers and decomposers. The **producers** are the organisms which manufacture food from inorganic substances. They are autotrophic organisms (ref 3.1), by far the most important of which are photosynthetic green plants. All other organisms which make up the community are **consumers**, and rely on producers, directly or indirectly, for their food. One group of consumers is given a separate name related to their role in the ecosystem. They are the **decomposers** comprising microorganisms, mainly bacteria and fungi, which live and feed saprobiontically on dead organic materials, and release simple reusable substances such as inorganic ions back to the environment. They are particularly important to any ecosystem because they ensure that inorganic nutrients are recycled.

Trophic levels, food chains and food webs

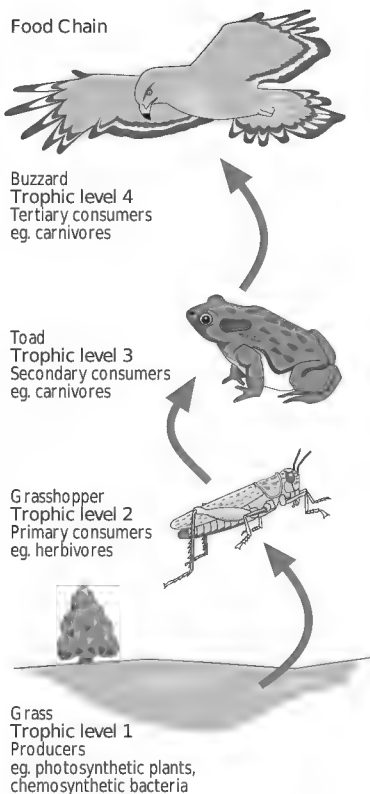
The green plants which constitute the base of most ecosystems convert a small part of the sun's energy, through the process of photosynthesis into a stored chemical form. This is the direct origin of food for herbivores and is ultimately the only source of energy for every other living organism. The sequence of organisms from producers through the chain of consumers is known as a **food chain**.

One way of determining the sequence of events would be simply to observe organisms feeding in captivity, for example pond organisms could be kept in an aquarium, but this method is not only time consuming, it is open to misinterpretation, since the same results may not apply in a natural ecosystem. Some food chains have been partially established by the analysis of gut contents, but this is a method which is only suitable for those organisms which have hard parts like a shell or exoskeleton which are not digested. More sophisticated methods of analysis include the labelling of plant food with radioactive isotopes like P^{32} which can be sprayed onto leaves in the form of phosphate. The organisms in the suspected food chain can then be tested for the presence and relative amount of P^{32} in their body.

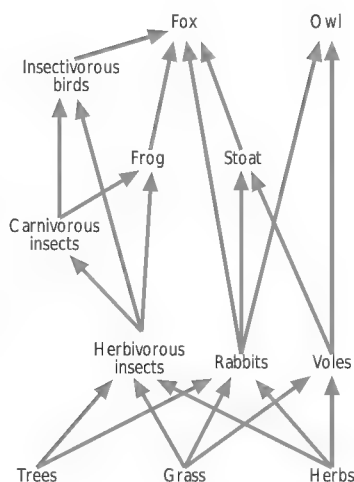
Food chains always start with a **producer**. Herbivores are the **primary consumers** and subsequent organisms higher up the food chain form **secondary consumers**, **tertiary consumers** and so on. These feeding levels are called **trophic levels**, with the producers making up the first trophic level, and herbivores the second trophic level etc. It is very rare to find a chain of more than five or six organisms because the amount of available energy is greatly reduced at each trophic level (see section 3.3)

In natural ecosystems, food chains present much too simplified versions of feeding relationships. The buzzard, for example, does not depend exclusively on rabbits for its nutritional needs, but will eat other organisms as well such as voles, mice and amphibia. A very complex network of interrelated food chains exists which is best illustrated by a **food web**. Since a food web of this kind is based on green plants it is called a **grazing food web**. Grazing food webs omit some very important organisms, namely decomposers which exist within a food web of their own (the **detritus food web**). Another group of organisms which are also present in communities and which cut across all the trophic levels of a grazing food web are the parasites. A complete picture of feeding relationships should therefore be composed of three interlinking food webs, the grazing food web, the detritus food web and the **parasitic food web**.

Food Chain



Arrows represent flow of energy



3.3

Energy Flow

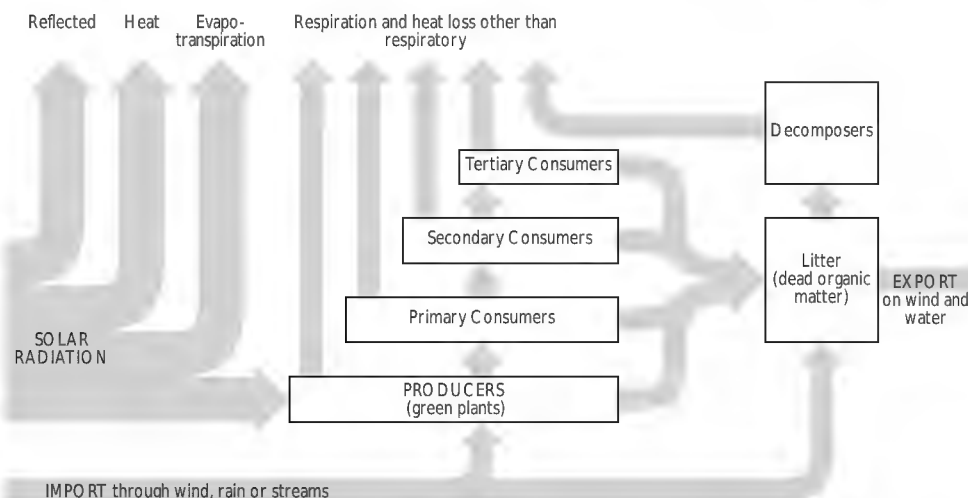
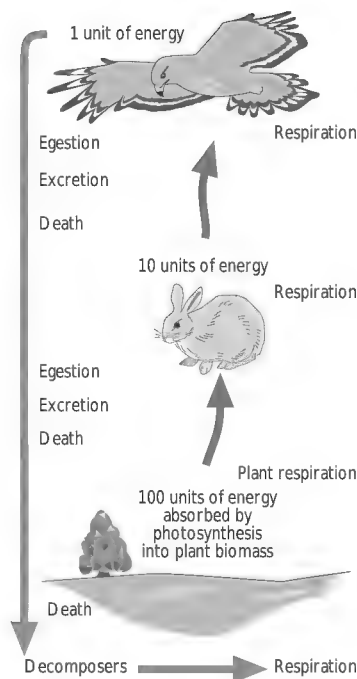
Content

- ▼ The conversion of carbon dioxide and water to glucose and oxygen, using energy from sunlight in photosynthesis and the absorption of light energy by chlorophyll.
- ▼ The role of producers, consumers and decomposers in food chains and food webs.
- ▼ The quantitative analysis of food chains using pyramids of numbers, biomass and energy;
- ▼ The transfer of energy through food chains and food webs and why energy is lost between trophic levels.
- ▼ Productivity, gross primary production and net primary production.

Photosynthesis, producers and consumers

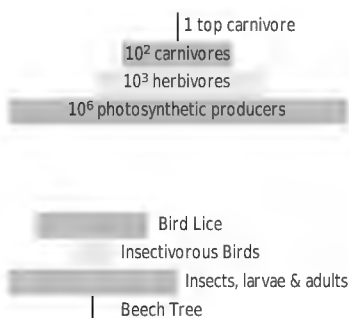
As you have seen in 3.2, all of the food materials generated within an ecosystem are manufactured by producers, autotrophic organisms which can produce organic compounds from simple inorganic substances such as carbon dioxide and water using an external source of energy. Green plants are the most important producers. Light energy is absorbed by chlorophyll, and converted to chemical energy within the chemical bonds of organic compounds e.g. glucose in the process of photosynthesis. This organic material and its energy is exploited by other organisms, the consumers. Consumers are **heterotrophic** organisms which cannot produce their own food from simple inorganic sources using external sources of energy, and must obtain a supply of ready-synthesised organic compounds from other organisms.

The inorganic materials are continually recycled, but ultimately all the energy originally absorbed by the chlorophyll in photosynthesis is lost as heat. Energy is therefore described as flowing through an ecosystem, and depends on continual input from the sun.



Pyramids of numbers, biomass and energy

The organic materials containing chemical energy are passed from organism to organism through food chains and webs. These materials are used to produce the biomass of the organisms in the food chains and webs, and as a source of energy for all their activities. As the result of inefficiencies of energy conversion and its use, a certain amount of energy is lost as heat back to the environment. If the different consumers in an ecosystem are arranged in their feeding sequence, from producers to herbivores to carnivores they form ecological pyramids. Generally the organisms in grazing food webs form a **pyramid of numbers** when arranged in their trophic levels. Predators, for example, tend to be larger than the animals they eat and as a result of the inefficiencies described above, they consume many of them during a single life span. It follows that there must be more prey than predators.



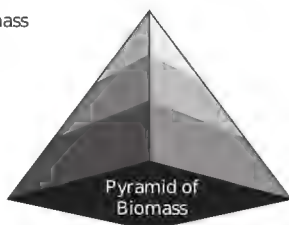
Obvious exceptions to this general principle are where the producers, being trees or large plants are larger and fewer in numbers than the herbivores (primary consumers) they support. A more accurate representation is a **pyramid of biomass** where the producers form the largest mass and the top carnivores, the smallest. In this pyramid, biomass is taken to mean the total amount of organic matter at each trophic level measured in grams dry mass per m^2 .

Pyramid of biomass

Carnivores

Herbivores

Plants in old fields



0.1 g dry wt m^{-2}

0.6 g dry wt m^{-2}

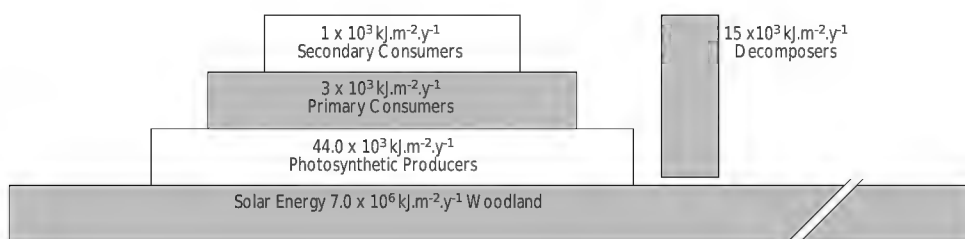
470 g dry wt m^{-2}

◆ CHECKPOINT SUMMARY

- ◆ The biosphere is that zone of the earth and its atmosphere that supports life
- ◆ An ecosystem is a more or less well defined region in which three components: biotic (living organisms), climatic, and edaphic (geology, soil and water) interact e.g. a fresh water pond
- ◆ Habitat means 'home' or 'address' within an ecosystem. The three primary 'drives' - to feed, to protect, to reproduce must be satisfied by the habitat e.g. leaf litter in a woodland
- ◆ These definitions are fairly arbitrary and artificial with many overlaps and anomalies
- ◆ They are only useful if they clarify discussions of problems in ecology, and too much emphasis should not be put on their definition for its own sake
- ◆ Producers 'produce' the organic matter on which all life depends. Virtually all producers are photosynthetic, converting light energy from the sun into the stable chemical energy of organic compounds
- ◆ Consumers 'consume' producers and each other to obtain a supply of ready-made organic material
- ◆ Feeding relationships can be considered as food chains and webs with organisms at different feeding or trophic levels, although organisms can feed at more than one level
- ◆ Typically there is a maximum of four trophic levels in a food chain as a result of the losses of material and energy at each level.

Unit 3: Energy and the Environment

Pyramids of biomass give a quantitative assessment of the ways in which food is passed through the trophic levels. However, biomass measurements change over the course of a year with the seasons; leaf fall in autumn, for example, produces disproportionate amounts of dead matter and alters the balance of organisms. More importantly, biomass is not directly comparable between different feeding groups, e.g. one gram of cows' milk is not comparable with one gram of grass. The best units of measurement are energy units (kJ per m² per year) and on this basis, a **pyramid of energy** can be constructed which accurately compares the energy transfer between each trophic level, including the initial transfer of sunlight by the producers, but the figures for this are difficult to obtain and process.



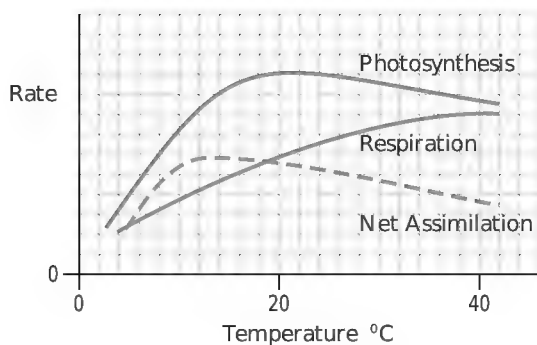
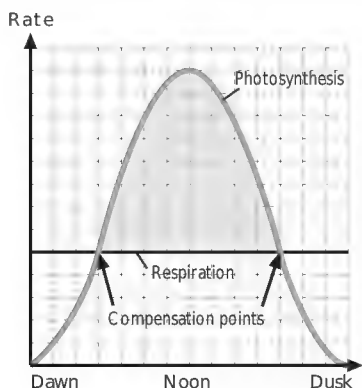
◆ CHECKPOINT SUMMARY

- ◆ Carbon dioxide and water are converted to glucose and oxygen, using energy from sunlight in photosynthesis and light energy is absorbed by chlorophyll and its accessory pigments
- ◆ In addition to producers and consumers, decomposers have a key role in the recycling of matter e.g. carbon and nitrogen cycles
- ◆ Decomposers reduce dead organic matter to simple inorganic compounds, e.g. carbon dioxide, and ammonium ions, which can be reabsorbed by producers and progress through food webs and chains again
- ◆ Food chains can be described quantitatively by means of pyramids of numbers, biomass and energy
- ◆ Pyramids of number may be inverted in certain cases e.g. thousands of aphids (greenfly) feeding on a single bean plant
- ◆ Pyramids of biomass avoid this anomaly and are always the right shape, at least if the biomass is calculated as dry biomass
- ◆ Pyramids of energy are similarly always the right shape
- ◆ The efficiency of energy transfer between trophic levels is typically less than 10% due to losses in conversion
- ◆ Photosynthetic producers only trap a small fraction of the available energy of sunlight, inefficiencies of digestion and absorption mean that most organic matter is not assimilated by consumers
- ◆ Energy losses as heat as a result of the inefficiencies of cell respiration also occur.

Productivity

The transfer of food energy from one organism to another is always wasteful. Each organism has its own energy requirements and releases heat to the environment as a result of its metabolism, especially movement. Other losses occur in the faeces and through nitrogenous excretion. Note that energy conversions work in one direction only. The sun's energy is not recycled in ecosystems, but flows through the food webs in chemical form and out of them as heat.

The efficiency with which the plants of an ecosystem convert light into food energy (**productivity**) can be estimated by collecting samples of plant material over a period of a year from selected sites. The material is weighed, dried to constant mass, and then burned in a calorimeter to give a measure of its energy content. In this way it is possible to estimate the amount of energy produced in a measured area of land over the period of a year. This is referred to as **gross primary production** and is measured in $\text{kJ}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$. Plants use some of this energy for their own growth purposes. Therefore the quantity available to consumers is called the **net primary production**.



◆ CHECKPOINT SUMMARY

- ◆ Productivity refers to the rate at which energy can be stored in organic substances by producers and has two sub-divisions
- ◆ Gross primary production refers to the rate at which energy is stored by plants
- ◆ Net primary production refers to that which is in excess of the plants own respiratory requirements and is potentially available to the next trophic level.

3.4

Recycling of Nutrients

Content

- ▼ The water cycle.
- ▼ The role of microorganisms, carbon sinks and carbonates in the carbon cycle.
- ▼ The stages in the nitrogen cycle and the role of microorganisms in the cycle as illustrated by decomposers, nitrifying bacteria (*Nitrosomonas*, *Nitrobacter*), nitrogen-fixing bacteria (*Rhizobium*, *Azotobacter*), and denitrifying bacteria (*Pseudomonas* and *Thiobacillus*).
- ▼ The disruption of the carbon and nitrogen cycles by human activities.

Bio-geological Cycles

Whilst energy flows through an ecosystem in one direction only and its supply must continually be renewed by the sun, the elements which make up the bodies of living organisms are fixed in quantity and are recycled and reused. When organisms die, their component molecules and ions are released back to the environment through the activity of decomposers. They may pass into the atmosphere as gases, enter the earth's oceans as dissolved minerals or become locked up in geological formations. Later, after millions of years or just a day or two, they may be taken up again by producers and made once more into components of a living organism.

The water cycle

97% of the earth's water is contained within the oceans, a varying proportion of which is frozen solid at the poles. The quantity available to living organisms in terrestrial environments depends upon the rate at which water leaves the oceans and returns to it. Water evaporates from the oceans and the water vapour eventually condenses as clouds and falls as rain. That which falls on land will run off the surface, and soak down to form the 'water table', some becoming trapped in deep lying porous rocks as underground reservoirs or 'aquifers'. Water also drains away into streams, rivers, lakes, and most eventually returns to the oceans. Vegetation, especially forests, plays an important part in returning water from the soil to the atmosphere as water vapour as a result of their transpiration. Forests have a significant effect on climate, and deforestation in hot dry climates and on poor soils can lead to the development of deserts. Water dissolves inorganic substances from the rocks and soils that it passes through, and these are the cause of the 'saltiness of the oceans' as only pure water evaporates, leaving the inorganic substances behind in solution.

The Carbon Cycle

The carbon cycle revolves around the balance between photosynthesis and respiration. The simple equations of each of these processes show the relationship between them:

Photosynthesis



Respiration



As can be seen, photosynthesis converts carbon dioxide (CO_2) into organic compounds such as glucose ($\text{C}_6\text{H}_{12}\text{O}_6$); and respiration breaks these down, releasing carbon dioxide into the environment. Respiration can be of living plants and animals, or of decomposers.

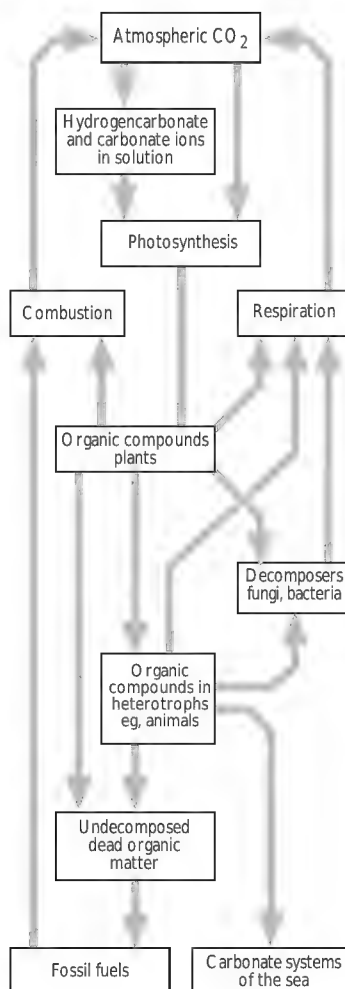
Not all of the carbon circulates freely in the cycle, much becomes trapped in 'carbon sinks' where it is removed for varying amounts of time from free circulation around the carbon cycle. The length of time spent in such 'carbon sinks' can vary considerably.

Some of the carbon taken in by marine animals in their food becomes incorporated into calcium carbonate, for example, in the shells of molluscs or the rocky substance of corals, and over an immense span of time may be locked up in geological formations of limestone and chalk. Calcium carbonate may also be formed chemically from solution. This geological reservoir of carbonate may, over the years, be eroded and washed back into rivers and oceans where, once more, the carbon, now in the form of carbonate ions, may be taken up by producer organisms.

Many trees are long lived and their organic compounds represent a 'carbon sink' which could endure for several hundred years. Forests are to be planted specifically to act as 'carbon sinks' in an attempt to remove excess carbon dioxide released into the air by combustion of carbon containing fossil fuels.

Much of the biomass of dead organisms does not decompose completely, but accumulates over millions of years as coal, oil and gas.

Carbon cycle



Human influences on the carbon cycle

The main effect of human activities on the carbon cycle is in the release of carbon dioxide into the atmosphere as a result of the combustion of fossil fuels such as coal, oil, and petroleum products in power stations and in cars. It took many millions of years for this carbon dioxide to be trapped by photosynthesis into organic compounds, which then slowly formed the deposits of coal and oil (carbon sinks), thus effectively removing it from the carbon cycle. However, the combustion of these fuels since the early 1900s (now at a rate of about 6×10^9 tonnes per year), releases carbon dioxide into the atmosphere at a rate faster than that at which it can be reabsorbed into the carbon cycle. One third of this annual production is absorbed by the world's forests through the process of photosynthesis, one third is absorbed somewhere (unknown) in the cycle, and one third increases the carbon dioxide concentration in the atmosphere. Pure air contains about 0.04 % carbon dioxide and it is calculated that this represents an increase of about 35% on that existing in the early 1900s.

Carbon dioxide is described as a **greenhouse gas** (see section 3.6) contributing to a layer in the upper atmosphere which traps some of the sun's radiant heat. Incoming radiant energy from the sun is of a wavelength short enough for about 70% of it to penetrate the greenhouse layer. Some of this energy serves to warm the earth's surface. Radiant energy is emitted back from the earth's surface in the form of a longer wavelength which does not pass so readily through the greenhouse layer but becomes trapped and redirected back to earth. The thicker the layer of greenhouse gases, the more the earth will warm up, an effect called **global warming**. Scientific models and predictions of the effect of increasing amounts of carbon dioxide in the atmosphere are notoriously unreliable in predicting the rate of global warming, but there is no doubt that the arguments revolve around 'when' and not 'if'.

◆ CHECKPOINT SUMMARY

- ◆ The geological water cycle involves the evaporation of water into the atmosphere and its precipitation from the atmosphere (rain, snow, hail etc)
- ◆ Water is essential for life and living organisms exploit various water supplies. Transpiring plants play a major part in drawing water from the soil and evaporating it to the air
- ◆ Much water drains away to deep lying deposits of porous rocks (aquifers) where it is essentially removed from the water cycle
- ◆ The carbon cycle involves the cycling of carbon from carbon dioxide in the atmosphere (or hydrogen carbonate ions in aquatic ecosystems) to carbon containing organic compounds and back again
- ◆ Photosynthesis converts carbon dioxide into organic materials which are exploited by consumers (and decomposers) and move through food chains and webs
- ◆ Respiration of living organisms (including that of decomposers) releases carbon dioxide back to the atmosphere
- ◆ Long living organisms e.g. trees act as temporary carbon sinks which remove carbon from the cycle for a period of time. More permanent sinks are represented by fossil fuels (coal and oil), and carbonates of shelled organisms which form chalk and limestone deposits
- ◆ Microorganisms acting as decomposers play a major role in releasing carbon back into the cycle as carbon dioxide
- ◆ Man now has a considerable effect on the carbon cycle by the combustion of fossil fuels (coal and oil) which releases carbon dioxide from these sinks in a very short time.

The Nitrogen Cycle

Nitrogen is a vital component of protein, ATP and nucleic acids in living organisms, making up about 3% of the total body mass of humans. Nitrogen gas composes 80% of the atmosphere but only a select group of microorganisms called nitrogen fixers can actually use this source. Plants take up nitrogen in the form of nitrates and ammonium ions from the soil, combining them with carbohydrate molecules synthesised by their leaves to make the protein, nucleic acids and other compounds that they need. Most other organisms take in nitrogen in this organic form through the food chain.

The principal conversions in the nitrogen cycle are carried out by bacteria between the three 'reservoirs' of nitrogen and its compounds, namely the atmosphere, the soil (or water) and living organisms.

From nitrogen gas to ammonia (NH₃) - nitrogen fixation

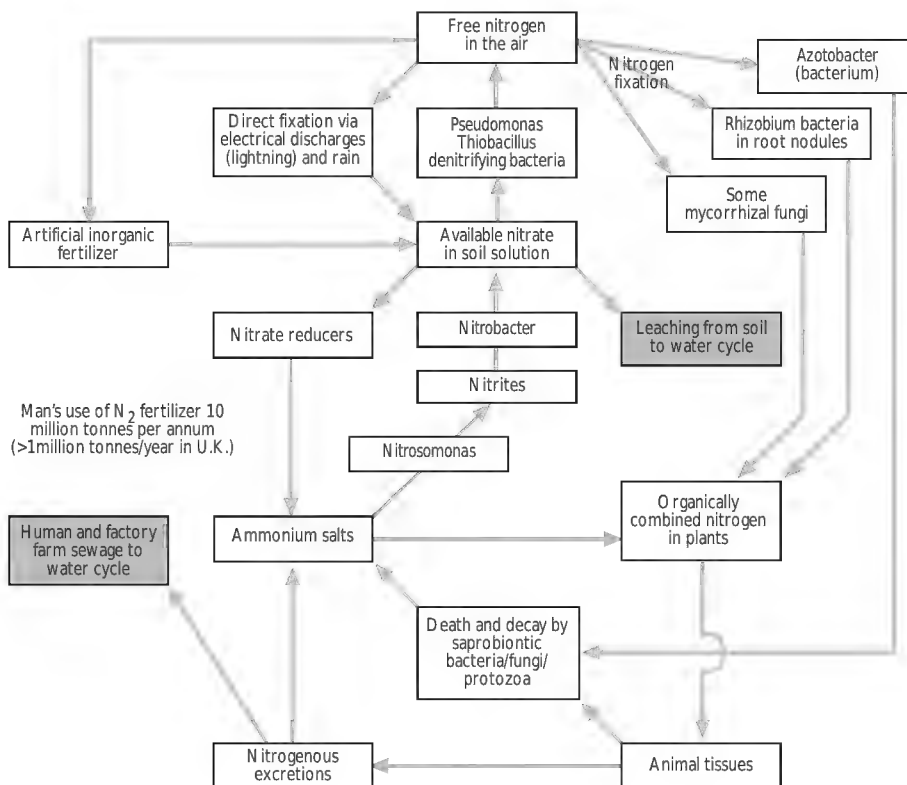
It is possible to make ammonia from gaseous nitrogen and hydrogen in the laboratory by combining them at high temperatures and pressures. This process is exploited commercially in the manufacture of nitrogen based fertilisers such as ammonium nitrate. **Nitrogen fixing bacteria** such as *Rhizobium* and *Azotobacter* can perform the same process at normal temperatures and pressures by means of the enzyme **nitrigenase**. They use the ammonia to make proteins and other organic nitrogen containing materials. One group of nitrogen fixing bacteria which includes *Rhizobium* (ref 3.1) forms a mutually beneficial mutualistic relationship with plants of the bean and pea family (**Papilionaceae**). *Rhizobium*, like *Azotobacter*, can live freely in the soil but it also penetrates the roots of these plants causing tumorous nodules to grow. Inside the nodules, the bacterial cells multiply, absorbing organic nutrients from the plant and giving, in exchange, a supply of fixed nitrogen.

From organic matter to nitrates in the soil - nitrification

Dead animals and plants, excreted materials, and faeces are broken down in the soil and water by decomposers. Proteins are digested in this process and the amino group containing nitrogen is split off from the resulting amino acids in the form of ammonia (NH₃). This process is called **deamination**. The activity of decomposers results in a pool of ammonia and ammonium compounds and this can be used as an energy source by a group of bacteria called **nitrifying bacteria** which includes the organisms *Nitrosomonas* and *Nitrobacter*. In contrast to green plants which derive their energy from the sun (**photoautotrophs**), *Nitrosomonas* and *Nitrobacter* use the energy derived from the oxidation of ammonium ions to nitrites and nitrates respectively. They are **chemoautotrophs** (ref 3.1).

From nitrates to nitrogen gas - denitrification

A third group of bacteria, called **denitrifying bacteria** use nitrates as a source of oxygen for their respiration. These organisms, which include *Pseudomonas* and *Thiobacillus* species are able to survive in soils which are waterlogged and lacking in oxygen and they release nitrogen gas as a waste product to the atmosphere, completing the nitrogen cycle.



Human influences on the nitrogen cycle

In nature, nitrogen fixation occurs faster than denitrification in all but winter waterlogged soils. Human activities add nitrogen compounds to the soil and water. There are three main sources of this nitrogen: fertilisers, animal excreta and domestic sewage, all of which lead to unnaturally high levels of nitrates in the water which may drain off the land and enter rivers and lakes.

High nitrate levels in rivers and lakes stimulate the rapid growth of water plants, particularly microscopic algae. The growth of algae can be so extreme as to cause **algal blooms** (see section 3.6) which block out the light for other photosynthesising life forms and clog up filters in water purification plants. The end result of so much plant life is an equivalent excess of dead plant material which, in turn, stimulates a population explosion of aerobic decomposing bacteria. As the bacteria multiply and respire, they use up the available oxygen supply in the water. Ultimately, the water becomes depleted of animals like insect larvae and fish which require high oxygen levels, supporting instead increasing numbers of anaerobic microbes. Still water of this type becomes stagnant and smells of methane and hydrogen sulphide, the waste products of anaerobic bacteria.

The process of the addition of excess nitrates (and other inorganic nutrients e.g. phosphates) to rivers and lakes is called **eutrophication** (ref. 3.6). It occurs naturally in lakes which gradually accumulate increasing quantities of inorganic nutrients from their feeder streams and rivers. Human activities however vastly accelerate the process. It is estimated, for example that Lake Erie in Canada would have taken another 15 000 years to reach the its present state of eutrophication had it not been for the activities of humans.

Potentially, nitrates are one of the most serious of all pollutants of drinking water, as the soluble forms are not removed by the usual treatment process. There are vast amounts of nitrates slowly percolating down towards the underground water stores or **aquifers** which provide about 30% of the water supplies in Britain. As more and more aquifers become polluted with dangerous levels of nitrate, increasing attention is paid to the problems of nitrate removal at water purification works. Nitrates can be reduced to nitrites in the anaerobic conditions of the gut (particularly in the only slightly acid stomach of babies). The nitrites can oxidise the iron in haemoglobin to a form which cannot transport oxygen in the blood. This can produce a fatal anaemia in infants. Another danger is that of nitrites reacting with other compounds in the gut to form cancer forming nitrosamines.

◆ CHECKPOINT SUMMARY

- ◆ The principle conversions in the nitrogen cycle are between the three reservoirs of nitrogen and its compounds: the atmosphere, soil and water; and living organisms
- ◆ Nitrogen fixing microorganisms, e.g. *Rhizobium* bacteria can convert nitrogen to nitrogen containing organic compounds such as amino acids which are the building blocks of proteins
- ◆ *Rhizobium* forms a mutualistic association in the root nodules of certain plants (Papilionaceae)
- ◆ Dead organic matter decomposes and releases nitrogen containing compounds, e.g. ammonia, and ammonium compounds
- ◆ Chemosynthetic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* use these as a source of energy for their synthetic processes, which result in the production of nitrate ions
- ◆ Plants take up ammonium and nitrate ions and combine them into amino acids and proteins, and other nitrogen containing compounds, e.g. ATP and DNA
- ◆ Animals consume plants and each other and these nitrogen containing compounds form an essential part of the diets of consumers
- ◆ Animals die and decompose and the cycle continues
- ◆ Anaerobic denitrifying bacteria convert nitrates back to nitrogen
- ◆ Man now has a considerable effect on the Nitrogen cycle by the use of artificially produced nitrate fertilisers.

3.5

Energy Resources

Content

- ▼ How energy resources can be managed in a sustainable manner.
- ▼ The use of fossil fuels as illustrated by coal and oil.
- ▼ The use of renewable energy sources, as illustrated by fast-growing biomass, gasohol from sugar, biogas from domestic and agricultural wastes.

Fossil Fuels

The energy resources which power domestic and industrial machinery may be divided into two distinct categories; those which originate from photosynthesis e.g. fossil and biomass fuels, and those which do not. The latter variety include nuclear, hydroelectric, solar, wind, wave and volcanic power, all of which, with the exception of nuclear fuels, are dependent upon geographic location.

Most of the world's population depends on power generated from fossil fuels. In the process of photosynthesis, light energy trapped by chlorophyll in green plants is fixed in the C-C and C-H bonds of organic molecules synthesised from carbon dioxide and water. When biomass is burnt as fuel, the process of combustion reverses this sequence of events and the chemical energy in the organic matter is released as heat which may be used directly, or indirectly e.g. to generate electricity.

It is likely that the energy heating the filaments of your light bulbs was once locked up in organic molecules in plants which received the light of the sun many millions of years ago. Fossil fuels are the underground stores of biomass from previous ecosystems, compressed and changed in form from living material into coal, oil and gas. Most of the world's coal was formed some 300 million years ago in a period called the carboniferous period. The trees were not related directly to today's trees, but were giant ferns, now extinct. Over the geological ages, the remains of these trees were partially decomposed and then compressed under layers of new sediments. Oil deposits were formed by a similar process from the remains of marine animals and plants.

Biomass fuels from fast growing trees - a sustainable alternative to fossil fuels

The supply of fossil fuels can not be sustained indefinitely. It is therefore increasingly important that alternatives are developed to complement, or even replace the dwindling resources.

Fast growing biomass

Cutting trees for fuel is the oldest form of woodland management. Many trees sprout vigorous new shoots when cut, for example willow and eucalyptus. If the cut is made at the base of the tree the process is called **coppicing**, but where grazing animals such as deer can

destroy the young shoots, the cut may be made higher up the trunk (fig 3.5.2). This is called **pollarding**. Both practices leave characteristic traces lasting many hundreds of years in ancient woodlands. The practice of coppicing has been revived in recent years using specially selected, fast growing tree species, notably poplars and eucalyptus. The rate of growth is, in any case, naturally accelerated by coppicing because all the resources of an extensive root system are diverted into a few slender shoots, and the wood can be harvested every 3 to 5 years on a rotation basis. In the future, it is likely that new genetically modified trees will be developed which will be able to grow quickly in relatively hostile climates and soils quite unsuitable for any other form of agriculture. In less developed areas of the world, the planting of fast growing hardwood trees is essential to prevent soil erosion (ref. 3.6) in addition to supplying firewood for cooking.

Gasohol from sugar

The harvesting and processing of agricultural crops leaves large amounts of waste biomass in the form of leaves, straw and other semi-processed materials, some of which might be fermented into alcohol for use as fuel. So far the commercial exploitation of alcohol from biomass has proved largely uneconomic. The 'gasohol' project in Brazil in the 1970s was based on alcohol production from a waste material (molasses) derived from sugar cane processing. The resulting ethanol was mixed 20 parts to 80 of petrol and used in cheaply converted car engines. Any benefit to the Brazilian economy from reduced fossil fuel imports, however, was quickly counterbalanced by the loss of revenue from selling the molasses to the international animal feed market, so the project floundered. The prospects are different for the future as new, genetically modified, varieties of yeast explode onto the biotechnology market. It is conceivable that almost any organic material might one day become a suitable substrate for commercial fermentation.

Biogas from domestic and agricultural waste

When waste is disposed of in landfill sites, the carbohydrate, protein and fat components of the organic matter are hydrolysed by aerobic microorganisms to produce acetate, carbon dioxide and hydrogen. In the process the available oxygen tends to be used up, and anaerobic bacteria take over to complete the decomposition of these compounds to methane and carbon dioxide. Methane is a valuable fuel (biogas) which burns with a colourless flame producing only carbon dioxide and water. A possible 40m³ of biogas could be produced by each tonne of waste, but recovery of this valuable product is relatively inefficient at present. Landfill biogas remains an important potential replacement for fossil fuels in both rich and poor countries.

The technology for collecting biogas is much more easily put into practice in sewage works where solid and semi-liquid organic matter is pumped into underground digester tanks. Similar systems can be installed on a smaller scale for the conversion of domestic and agricultural waste into usable fuel but the cost of construction and maintenance must be balanced against any concept of 'free' biogas energy.

◆ CHECKPOINT SUMMARY

- ◆ The use of fossil fuels (oil and coal) is unsustainable as they are finite resources. They represent the accumulation of millions of years of photosynthetic activity, and their combustion over the last century or so has returned all the carbon from these 'sinks' to the atmosphere
- ◆ The carbon cycle has become distorted and the carbon dioxide levels in the atmosphere are rising
- ◆ Energy resources can and need to be used in a sustainable manner
- ◆ To do so use must be made of solar energy, wind, wave, hydroelectric schemes, and organic matter the combustion of which represents a carbon balance
- ◆ Fast growing biomass (eucalyptus trees), gasohol (alcohol) from cane sugar, and biogas from the fermentation of domestic and agricultural wastes, release carbon dioxide by their combustion in proportion to that which was absorbed by photosynthesis in their production.

3.6

Human Influences on the Environment

Content

- ▼ The causes and effects of deforestation and desertification, with particular emphasis on communities, biodiversity and sustainable management.
- ▼ Atmospheric pollution (acid rain and greenhouse effect)
- ▼ Water pollution (effect of raw sewage and fertilisers on water quality, oxygen content and biodiversity, eutrophication, algal blooms).
- ▼ European legislation to control air and water quality.

Deforestation

Every year, large areas are deforested in order to create land for cultivation and to provide wood and charcoal for cooking. Once removed, overcultivation, overgrazing and the accompanying soil erosion change the soil conditions irreversibly so that regeneration of natural forest is impossible. It is estimated that the erosion of bare soil by wind and rain is 25 times more rapid than for land covered by a cotton crop, 4000 times more rapid than grassland and 32 000 times more rapid than forested land. In hilly regions, deforestation results in silt washing down with the rainwater into rivers, so that the river levels rise year by year causing annual floods in the plains and estuaries. Deforestation also has a major impact on local climate. Up to 50% of the water vapour of clouds above forests is contributed by transpiration. Without the trees, this water runs off into streams and rivers carrying with it valuable nutrients, leached from the soil. It is not recycled into the atmosphere.

The loss of natural vegetation and the accompanying loss of soil fertility affects the whole **community** of organisms which make up the biotic component of natural ecosystems. As you have seen (3.2), each individual population within a community is dependent on, and important to, a number of others. Intricate systems relate predators to prey, pollinators to flowering plants, consumers to producers. The loss of a single component can have dramatic knock on effects. For example, pollinating mechanisms can be so specific that the loss of a single pollinator in the ecosystem can result in the local extinction of an entire population of plants.

Biodiversity is the term used to describe the number of different interacting species supported by a particular habitat. In general, the richer the vegetation cover, the greater the biodiversity, but each community has complex interactions and different weak spots and these need to be understood if effective conservation management strategies are to be devised. At present the usual response of governments to the loss of wildlife habitats is the creation of living museums in the form of nature reserves and wildlife parks. The important question is rarely addressed, namely, how big does a nature reserve have to be to preserve biodiversity?

The answer is, much larger than is generally expected. Wandering herds require massive grazing areas and uninterrupted freedom of movement within these areas. The wildebeest and zebra which

migrate up and down the Great Rift Valley of East Africa between Tanzania and Kenya are threatened much more by human settlement than by the notorious crocodiles of the Mara river. Many of the animals most at risk of extinction are at the top of food chains. The hunting area of top carnivores such as tigers or eagles is very large but the reproductive area is much larger still. For populations to survive, genetic diversity through outbreeding is essential and isolated national parks do not answer this problem

Desertification

Natural deserts like the Sahara are created by global climate changes and are defined by the amount of annual rainfall received (less than 50mm). Settled human existence is not possible in such hostile conditions because the soil can not support food crops. However human settlement does occur on the fringes of these areas, although attempts to gain food and support from soils which are poor in nutrients to start with, and which suffer a combination of heat and drought often result in an expansion of the desert, a process called **desertification**. Desertification is the result of using arid and semi arid soils in non-sustainable ways to produce crops, and the underlying cause is the pressure of expanding human populations. The areas most at risk are tropical grasslands receiving between 200 and 600 mm rainfall per year in one short wet season.

The pressure for food and cash crops from overpopulated land results in too many crops being planted and harvested from the same soil, leaving insufficient time for the natural restoration of fertility. Overcultivation also leaves the soil bare for extended periods when it is vulnerable to erosion. The effect is particularly severe on hillside plots where sudden rains can create gulleys and land slips. As more land is used for cultivation, less is available for grazing livestock. Overgrazing eliminates the natural regeneration of trees and shrubs and it reduces the population of native grasses which are so important in binding and trapping soil particles. These tend to be replaced by temporary, shallow rooted species which appear and disappear with the rains.

One way of increasing food yields from arid soils is to irrigate the soil, but this invariably leads to a build up of salt deposits in the soil (**salinisation**) and, in solving one problem, it creates another. Irrigation water leaves a crust of salt as it evaporates from the soil surface and, over a period of time, this salt deposit is leached downwards by drainage until it reaches the water table. The only way to remove the surface crust is periodically to flood the soil, and provide adequate underground drainage channels to take away the accumulated salt along with the flood water. Without adequate drainage, flooding may raise the water table to the level of plant roots bringing with it toxic concentrations of salt. If proper concern is shown for the environment, desalination installations may be needed to treat the drainage water before it can be returned safely to a river, so, even in highly technical projects such as those in California, the real costs of irrigation can easily escalate beyond economic viability.

Pollution

A pollutant is any substance released into the environment as a result of human activities which causes harm. Some pollutants are directly toxic to humans and other organisms: others become harmful as they accumulate in unnatural quantities. Nitrate applied to a crop in the form of fertiliser, for example, is valued as a mineral nutrient: it becomes a harmful pollutant only if it leaches out of the soil into aquatic ecosystems.

Carbon dioxide and the greenhouse effect

Carbon dioxide is a major component of a layer of gases called 'greenhouse gases' which accumulate in the atmosphere. Other greenhouse gases include methane (ref 3.5), chlorofluorocarbons (CFCs), nitrous oxide and ozone. In a greenhouse, light energy passes through the glass and warms up the contents. Heat is prevented from escaping by the glass panels and, as a result, the space inside warms up. In a similar, but not identical way, the layer of greenhouse gases serves to warm the earth. It is calculated that without the greenhouse layer, the earth's average temperature would drop by up to 30°C.

Radiant energy from the sun is made up of a number of different wavelengths, from ultra violet (less than 400nm) to infra red (more than 700nm). Visible light includes all the wavelengths between these two i.e. 400 - 700nm. Light energy passes relatively easily through the gas layer to warm the earth's surface but heat energy radiating back from the earth consists of much longer wavelengths (4000 - 100 000nm) which do not pass through so easily. Much of this energy is instead absorbed and re-radiated back to earth, hence the warming effect.

There is no doubt that the amount of carbon dioxide in the atmosphere has increased dramatically over the last few decades, and records show distinct evidence of global warming, but it should not be assumed that there is a direct connection between the two - correlation between two factors is not proof of a cause and effect relationship. The risk is, as yet, unknown and unquantifiable, but the wisest policy is to take steps to minimise the risk by developing alternatives to fossil fuels.

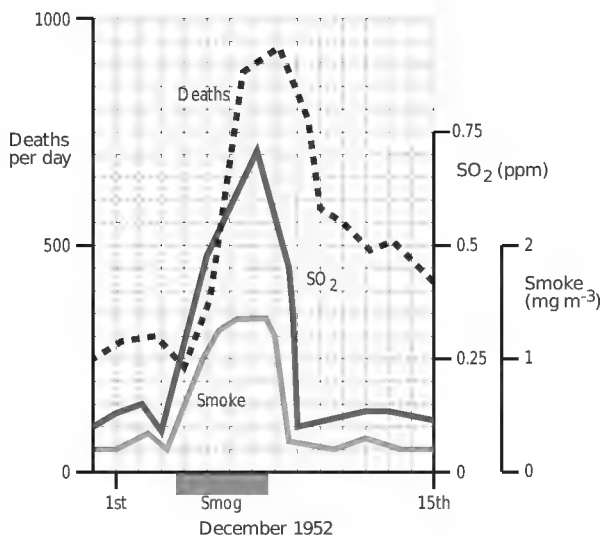
Acid rain

Rain is always slightly acidic. It contains carbon dioxide which dissolves to form carbonic acid creating a normal pH of about 5.6. The term acid rain is defined as rainfall with a pH below 5. It is formed as sulphur dioxide (SO₂) and nitrogen dioxide (NO₂), originating from the combustion of coal and oil, react with moisture in the air to form sulphuric and nitric acids respectively. The rain in central Europe has an average pH of 4.1 whilst water droplets in fog may be as low as pH 2.5. At these levels, acid rain can cause serious harm to human health. In December of 1952, for example, London was enveloped in a notorious fog which remained static due to unusual air currents.

The pH was estimated to be about 1.6 and 4000 people died from related illnesses. The cause of this disaster was identified as smoke from the countless chimneys of London but, in fact, the major source

of sulphur dioxide pollution is from coal fired power stations. Sulphur occurs as an impurity in coal (up to 3% by mass). Furthermore, the smoke from industrial chimneys may carry these gases hundreds of kilometres away from the original source so the effects of pollution extend over whole continents.

Pollution levels in the London smog of 1952



Acid rain lowers the pH of the soil solution where the excess H⁺ ions tend to replace ions such as Ca²⁺, K⁺ and Mg²⁺ held by the soil particles, which are essential for plant growth. These nutrients leach out and are lost in the drainage water. Nitrate (NO₃⁻) ions from nitric acid are not a major problem because they are taken up by plant roots and used as a nitrogen source, but sulphate (SO₄²⁻) ions move freely through the soil solution carrying H⁺ ions with them into surrounding water systems. Acid rain therefore has the effect of removing plant nutrients from the soil, but plants are affected in more direct ways as well. The leaves of evergreen plants, particularly coniferous trees, are protected by a waxy layer (cuticle) which is eroded by acid rain. Over a period, nutrients are also lost from the leaves causing a die back of the crown of the tree.

Acid rain can have even more drastic effects on lakes and waterways. The exoskeletons of crayfish and shrimp become soft and susceptible to fungal attack at pH levels below 5.5, and no fish survive at levels below 4.5. In studies on Scandinavian lakes the loss of brown trout and salmon was linked to two different consequences of acid rain. One was the denaturation of an enzyme, essential to the hatching of eggs. The other was the leaching of Al³⁺ ions into lakes from the surrounding soil which caused the secretion of large amounts of mucus by the fish gills. As a result gas exchange and osmoregulation became impaired and the fish died.

◆ CHECKPOINT SUMMARY

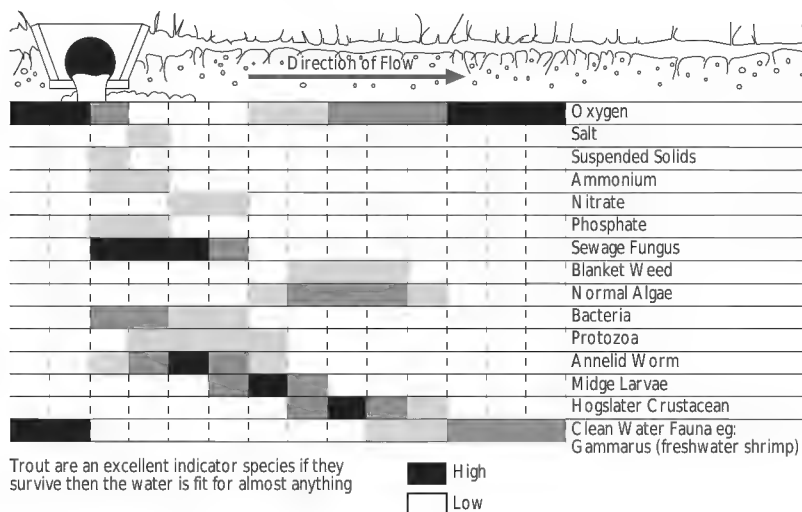
- ◆ Increasing population pressure and economic demands lead to deforestation. Removal of tree cover on poor soils can lead to the collapse of the entire ecosystem and the formation of deserts (desertification)
- ◆ Under less extreme conditions deforestation can lead to isolation of small patches of woodland which are insufficient to support the original forest communities with their rich biodiversity
- ◆ If the cleared areas are used for crop production there is a dramatic drop in the biodiversity and hence stability of communities, and massive monocultures are prone to pest attack
- ◆ Atmospheric pollution as a result of the combustion of fossil fuels results in acid rain (sulphuric and nitric acids), and greenhouse gases (e.g. carbon dioxide) which absorb solar radiation and lead to a warming of the atmosphere.

Organic pollution and eutrophication

Farmyard waste in the form of manure and silage liquid, and untreated domestic sewage contains large amounts of organic matter which can cause serious pollution problems if allowed to enter rivers and lakes. This material provides food for a multitude of anaerobic microorganisms in aquatic ecosystems and as these organisms complete the process of decomposition, they use up valuable oxygen supplies. Aquatic organisms may be classified according to their oxygen need; those with the greatest need are **indicator species** for the cleanest water, that is their presence indicates water unpolluted by organic matter.

The direct link between organic pollution and oxygen availability is the basis of a test for water purity called the **BOD** (Biological Oxygen Demand) test. BOD is the amount of oxygen required by microbes to decompose the organic matter present in a water sample. Water samples are collected in glass bottles and an initial measurement of their oxygen content is taken using an oxygen meter. The samples are incubated in the dark at 20°C for 5 days and then the oxygen content is re-measured. The difference between the two readings gives the BOD (in $\text{mg O}_2 \text{ dm}^{-3}$). It varies from 0 - 12 in clean rivers to 250 in untreated sewage.

The decomposition of organic matter releases inorganic nutrients into water systems which can be just as damaging to the environment (ref. 3.4). The presence of excess nutrients initiates a process called **eutrophication** (from the Greek words *eu* - well, *trophe* - fed) 'Well fed' algal populations can undergo rapid population 'explosions' into algal 'blooms' on the surface of the water, blocking light penetration and providing a further source of organic material at the end of the growing season. Fertilisers (3.5) and farmyard wastes are the main sources of inorganic nutrients, but even treated sewage can contain large quantities of phosphates from detergents.



European legislation for air and water purity

Anti-pollution measures to safeguard air and water purity tend to be long term, expensive, and unpopular with the commercial sectors. It is hardly surprising, therefore, that few national governments concern themselves seriously with environmental issues. Political pressure and national sentiments are generated more when the environmental threat crosses national boundaries. The European Community legislation focusses its attention mainly on the transboundary (international) pollution of air and water through international conventions and agreements, but it also translates these agreements into specific Directives which become binding on the member states, some examples of which are given below.

Water protection and management

International agreements and **conventions** exist with regard to the conservation of marine and coastal waters, and the major European rivers. These include currently, for example, a convention for the protection of the marine environment of the north eastern Atlantic, protocol concerning specially protected areas and biodiversity in the Mediterranean, and conventions of the International Commission for the protection of the rivers Elbe and Oder.

International agreements of this kind define areas of common interest but have less immediate effect than the **Council Directives** which tend to be much more specific, and thus easier to define and enforce, for example; regulations regarding minimum levels of drinking water purity from ground and surface sources, prohibitions on the discharge of hydrocarbons from boats, nitrates from agricultural land and mercury from chlor-alkali industries.

Council Directives must be adopted as law by member states after a given time, typically 18 months after the formulation of the legislation by the EC. It is then up to the Department of the Environment or equivalent bodies to enforce them in the individual European countries.

Monitoring of atmospheric pollution

As for air quality, European legislation may be divided into two broad categories: conventions and agreements about transboundary pollution and Council Directives to specify limits and controls within the member states. The major transboundary issues are sulphur dioxide and nitrous oxide emissions and their long range effects; the control of greenhouse gases; and the depletion of the ozone layer. Some Council Directives are aimed at the major industries, for example, testing and monitoring emissions of carbon dioxide, carbon monoxide, suspended particles, sulphur dioxide and oxides of nitrogen from chemical works and power plants; controlling the release of chlorofluorocarbons from foamplastics and refrigerant industries. Others have had a direct effect on daily life, for example, Directives about lead in motor fuels and the monitoring of pollutants from diesel engines for use in vehicles.

European legislation is not exactly watertight. The conventions have limited force because they are simply international agreements, and the Council Directives suffer from the time lag between formulation and adoption. If a member state 'breaks the rules' it can take a very

◆ CHECKPOINT SUMMARY

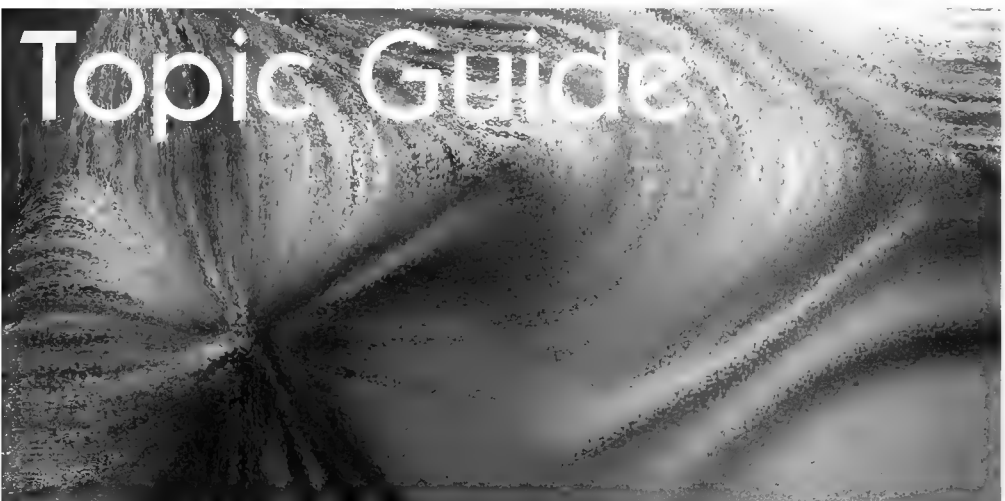
- ◆ Water pollution results from the release of the many toxic waste products of man into the water system
- ◆ Acid rain acidifies water and destroys aquatic ecosystems
- ◆ Raw human and animal sewage has a high organic content and its oxidation by aerobic microorganisms depletes water of its oxygen
- ◆ Run-off of excess nitrates and phosphates from artificial fertilizers in the soil cause eutrophication of the water which can trigger excess algal growth (algal blooms), which can deplete other essential nutrients, leading to death of the algae, their aerobic decomposition, and depletion of oxygen in the water
- ◆ Depletion of oxygen in aquatic ecosystems leads to the death of aerobic organisms and the collapse of the ecosystem into anaerobic conditions, which cannot be simply reversed by oxygenation
- ◆ European legislation exists to control air and water quality.

Unit 3: Energy and the Environment

long time for the rest of the community to exercise some form of censure. It can also be argued that environmental issues such as the greenhouse effect, ozone depletion and marine pollution are global, not just European.

Balancing these negative aspects, it should be remembered that Directives such as those controlling diesel fuel emissions, lead, nitrate and mercury pollution have measurably improved the quality of the air we breathe in our cities and the water we drink. On the wider scene, the focus by the EC on transboundary environmental pollution helps to create an impetus for international agreements on a global scale.

Biology or Biology (Human)



Unit 1 - Molecules & cells

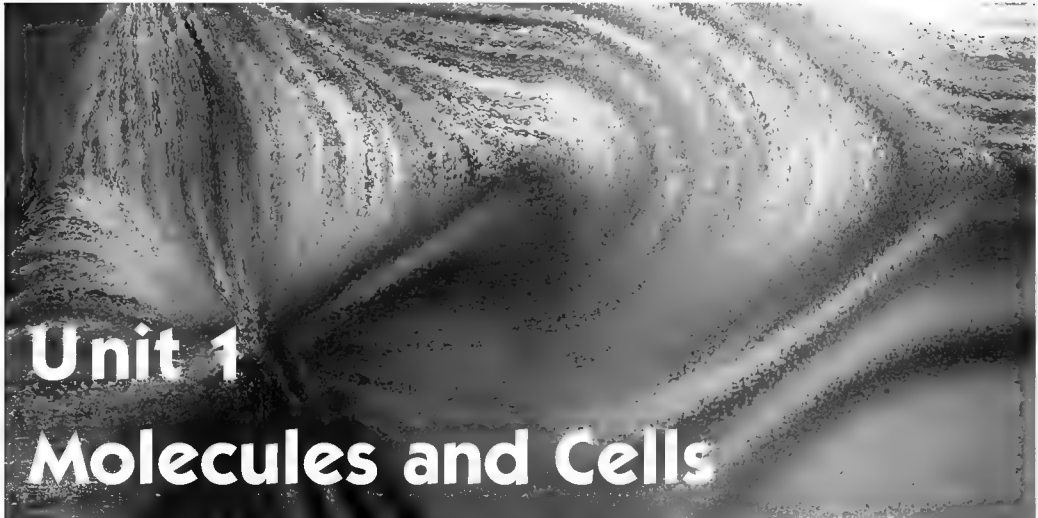
Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

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Topic Guide



1.1 Molecules

1.2 Enzymes

1.3 Cellular Organisation

1.4 The Cell Cycle

Unit 1

Molecules and cells

1.1 Molecules

Water

Topic Guide

Session: _____

Check List

- ▼ Water molecules are dipolar with an electronegative pole and an electropositive pole.
- ▼ The dipolar nature of water causes molecules to be attracted to each other by hydrogen bonds resulting in most of the key properties of water in relation to living organisms.
- ▼ Liquid at normal temperature and pressures, solid (ice) at 0°C, boiling point 100°C, providing a wide range as a liquid.
- ▼ It has high cohesion resulting in a strong surface film allowing small organisms to be supported on top or underneath it, and the ability for the water column
- ▼ 'Universal' solvent in which many substances dissolve.
- ▼ Water supports aquatic organisms, ice is less dense than water, therefore ice floats and organisms can survive beneath it.
- ▼ Low viscosity allows free flow for transport of materials inside and outside of organisms.
- ▼ Water rises in small bore tubes by capillarity e.g. important in water transport in plants.
- ▼ Being incompressible water provides a hydrostatic skeleton, e.g. earthworm body cavity, human abdominal cavity
- ▼ Latent heat of evaporation results in a cooling process e.g. sweating
- ▼ Water has a high specific heat which is important in temperature control of aquatic environments and internal fluids.
- ▼ Transparency allows the transmission of light e.g. for photosynthesis
- ▼ Inorganic ions dissolve freely in water and have a wide and varied role in living organisms.

Student Activity

Materials

- 2 thermometers with small piece of blotting paper and 2 rubber bands
- Slices of cucumber (5mm wide)
- Small squares of cellophane (2-3cm)
- Pieces of capillary tubing (6-10 cm), and tubing of wider diameter
- Collection of 5p coins

Procedure

Put cucumber slice into water and see how many 5p coins it take to sink it

Put cellophane on top of water and see how many coins it takes to sink.

Support tubes upright in water and measure how far the water meniscus rises

Attach small piece of blotting paper to the sensitive end of each thermometer with elastic bands, having

first wetted one of the pieces of blotting paper. Blow on the paper and compare temperatures.

Report on how particular water property (buoyancy, surface tension, capillarity, latent heat of vapourisation) might be of use to living organisms.

Set work

Suggest improvements of the simple investigations that you carried out.

Notes: _____

Unit 1

Molecules and cells

1.1 Molecules

Carbohydrates

Topic Guide

Session: _____

Check List

- ▼ The simplest carbohydrates are monosaccharides (single sugars) which have varying numbers of carbon atoms e.g. pentoses have 5C and hexoses 6C.
- ▼ Monosaccharide have a role as units (monomers) in the formation of long chains of repeating units (polymers).
- ▼ Simple formula for glucose - $C_6H_{12}O_6$
- ▼ In straight chains in dry powder form.
- ▼ Forms ring structure in solution.
- ▼ alpha and beta glucose are isomers differing in the 3D arrangement of their atoms.
- ▼ Monosaccharides (glucose, fructose and galactose) combine together with the elimination of water to form glycosidic bonds - a condensation reaction.
- ▼ Glucose and fructose combine to form sucrose; glucose and galactose combine to form lactose; and two molecules of glucose combine to form maltose.
- ▼ Glycosidic bonds are broken by the addition of the elements of water across the bond (hydrolysis reaction).
- ▼ Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains).
- ▼ Both being long chains (polymers) of alpha glucose molecules.
- ▼ When combined the alpha glucose molecules have their oxygen bridges on the same side of the chain, hydrogen bonds form between them and cause the chain to coil into a helix.
- ▼ Starch molecules are relatively insoluble in water.
- ▼ Glycogen ('animal starch') is a glucose polymer found in the liver and muscles of animals.
- ▼ Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix, but form hydrogen bonds with other adjacent chains to make flat ribbons which form fibres.

Student Activity

Materials

- Molecular model of alpha and beta glucose.
- Gravy powder, bunsen, gauze, and beaker with water
- Small tasting samples of glucose, fructose, sucrose in powdered form on sterile filter papers
- ☐ OHT Monosaccharides and disaccharides
- ☐ OHT Polysaccharides

Procedure

- ☐ OHT Monosaccharides and disaccharides recaps structure of alpha and beta glucose
 - Observe molecular models of glucose.
 - ☐ OHT Polysaccharides
- To illustrate the principle of starch hydration, dissolve the gravy powder in a small volume of water, then heat gently in the beaker (safety glasses etc). Describe how and when it thickens,

then discuss why this happens.

'Blind' tasting of fructose, glucose and sucrose.

Put the substances in order of sweetness. Discuss how properties can vary with small molecular differences. (Caution - do not use galactose. Some people are intolerant).

Set work

Make molecular diagrams to show the structure of alpha and beta glucose, maltose, starch and cellulose.

Notes: _____

Unit 1

Molecules and cells

1.1 Molecules

Lipids

Topic Guide

Session: _____

Check List

- ▼ Lipids include fats, oils, waxes, phospholipids and steroids.
- ▼ Triglycerides are composed of three (tri) fatty acids combined by condensation reactions to form ester bonds with glycerol.
- ▼ Fatty acids have long hydrocarbon chains and a carboxyl group (COOH).
- ▼ Saturated fatty acids (and hence saturated fats) have no double bonds in the hydrocarbon chain which is 'saturated' with hydrogen.
- ▼ Unsaturated fatty acids have one double bond.
- ▼ Polyunsaturated fatty acids have two or more double bonds.
- ▼ Fats (triglycerides) are energy rich storage products in plants and animals.
- ▼ Lipids provide waterproofing in plant cuticles and animals e.g. insect cuticles, provide mechanical protection and insulation as sub-cutaneous fat in mammals, and bouyancy in aquatic mammals.
- ▼ Phospholipids are formed from triglycerides by the replacement of one fatty acid by a phosphate group.
- ▼ Phospholipids form the structural basis of biological membranes by forming a bilayer.
- ▼ The bilayer is formed with their hydrophobic poles adjacent and their hydrophilic poles in contact with the aqueous phase.

Student Activity

Materials

- Range of fats, oils and waxes
- OHT Structure of triglyceride
- OHT Phospholipids and the bilayer

Procedure

Observe the range of fats, oils and waxes.

Tabulate the location and functions of fats, oils, waxes, phospholipids, cholesterol and steroids in living organisms.

Set work

Make notes to explain the structural differences between saturated and non-saturated fats

Notes: _____

Unit 1

Molecules and cells

1.1 Molecules

Proteins

Topic Guide

Session: _____

Check List

- ▼ All amino acids share a common structure consisting of a hydrogen atom, an amino group (NH_2), a carboxyl acid group (COOH), and a 'R' group, all attached to a carbon atom.
- ▼ The 'R' group can range from a single hydrogen atom to a long complex chain. Thus the simplest amino acid has the formula of $\text{CH}_2\text{NH}_2\text{COOH}$.
- ▼ Amino acids combine in a condensation reaction which form a peptide bond, which is broken by hydrolysis (digestion).
- ▼ There are about 20 different types of amino acids found in proteins of living organisms.
- ▼ Proteins are polymers of up to 2000 amino acids (monomers) joined by peptide bonds (polypeptides).
- ▼ The combination of the 20 different types of amino acids gives rise to as many as 100 000 different types of proteins in living organisms.
- ▼ The sequence of amino acids in the polypeptide chain determines the primary structure of proteins.
- ▼ Hydrogen bonds between adjacent NH_2 and COOH groups result in the secondary structure of either alpha helix or beta sheet. Both of these structures may occur in the same protein.
- ▼ Bonds that form between the 'R' groups determine the tertiary structure.
- ▼ Combination or association of two or more polypeptide chains determines the quaternary structure of a protein.
- ▼ Haemoglobin has a quaternary structure involving four polypeptide chains and four iron containing haem groups.
- ▼ The three dimensional structure of protein is vital for the activity of enzymes, all of which are proteins.
- ▼ Proteins with complex tertiary and quaternary structures are referred to as globular proteins, e.g. enzymes and some hormones e.g. insulin, and are metabolically active.
- ▼ Fibrous proteins are less complex proteins and largely structural in function e.g. collagen which forms the most common connective tissue in the human body e.g. in skin, bones, tendons, etc.

Student Activity

Materials

- Molecular models of two amino acids, one with an 'R' group of just one hydrogen atom, and one with a long chain.
- Popper beads.
- OHT Amino acid structure and peptide bond
- OHT Secondary and tertiary structures of proteins
- OHT Structure of haemoglobin

Procedure

Observe 3D models of amino acids.

Combine two to form a peptide bond.

Review the different R group bonds: hydrogen, ionic, disulphide and hydrophobic.

Set work

In what ways are the structure of Aspartame, insulin, collagen and haemoglobin similar.

In what ways are they different.

Explain why egg albumen changes from liquid to solid (egg white) when cooked.

Notes: _____

Unit 1

Molecules and cells

1.1 Molecules

Nucleic acids

Topic Guide

Session: _____

Check List

- ▼ DNA and RNA are long chain polynucleotide molecules with repeating sub-units of mononucleotides combined as a result of condensation reactions.
- ▼ Mononucleotides consist of a 5 carbon sugar, a phosphate, and an organic base.
- ▼ In DNA the sugar is deoxyribose and the organic base can be one of adenine, thymine, cytosine and guanine.
- ▼ In RNA the sugar is ribose and the organic base can be one of adenine, uracil, cytosine and guanine.
- ▼ RNA is a single stranded helix with base pairs of adenine-uracil and cytosine-guanine.
- ▼ There are three types of RNA - messenger, transfer and ribosomal.
- ▼ The DNA molecule is a double stranded helix with the two strands held together by hydrogen bonds between complementary base pairs adenine-thymine and cytosine-guanine.
- ▼ DNA carries out semi-conservative replication in which each strand of the original molecule acts as a template for the construction of a new one, so that each new double stranded molecule of DNA consists of one original strand and a new complementary strand.
- ▼ The synthesis of new strands of DNA is catalysed by enzymes, including DNA polymerase.
- ▼ A gene is a length of DNA which carries the genetic information for the synthesis of a single polypeptide chain. The gene determines the primary structure of the polypeptide, that is the sequence of amino acids.

Student Activity

Materials

- DNA molecular model
- OHTs showing structure of DNA, RNA and semi-conservative replication (with DNA polymerase)

Procedure

Use the 3D model of DNA structure to clarify any problems with envisaging the 3D structure from 2D diagrams.

Set work

What does 'semi-conservative replication' mean? Explain a piece of experimental evidence for semi-conservative replication.

Notes:

Unit 1

Molecules and cells

1.1 Molecules

Nucleic acids

Topic Guide

Session: _____

Check List

- ▼ The sequence of nucleotide bases on one strand of the DNA molecule carries the genetic code for the synthesis of proteins and hence ultimately living organisms.
- ▼ Three bases (a triplet codon) code for one amino acid.
- ▼ There are 64 (4^3) possible combinations of any three from four bases, but only 20 amino acids to be coded for.
- ▼ Amino acids are coded for by more than one triplet codon and the code is said to be 'redundant' or 'degenerate'.
- ▼ A gene is a sequence of nucleotide bases of a DNA molecule which codes for a polypeptide.
- ▼ A gene for a polypeptide has a specific 'start' codon which thus sets the order of all the subsequent triplet codons.
- ▼ Thus the code is non-overlapping i.e. a base can only be 'used' in one triplet codon.
- ▼ Only a fraction of the nuclear DNA contains genes coding for proteins, the rest consists of so-called 'junk' DNA the function of which is not understood.
- ▼ Nuclear DNA with the genetic code never leaves the nucleus in eukaryotic cells.
- ▼ The genetic code (a gene) for a polypeptide is copied (transcribed) into mRNA which leaves the nucleus and associates with the ribosomes.
- ▼ The ribosomes 'read' the genetic message on the mRNA, and tRNA delivers amino acids in the sequence determined by the code.
- ▼ There are 20 different types of tRNA, each specific to a particular amino acid.
- ▼ Each tRNA has a specific binding site at which the specific amino acid combines and an anti-codon which matches the specific codon for that particular amino acid.
- ▼ The amino acids combine by means of peptide bonds to give a polypeptide chain.
- ▼ The polypeptides subsequently form proteins.
- ▼ As enzymes are proteins their synthesis is controlled by DNA.

Student Activity

Materials

- ☐ OHT Transcription and translation
- ☐ OHT Table of amino acid codons
- ☐ OHTs showing base sequence / gene code

Procedure

- ☐ OHT Transcription and translation
- ☐ OHT Table of amino acid codons

Can be used to revise transcription and translation.

Set work

DNA replication, transcription, and mRNA translation all require enzymes to catalyse their reactions. Explain the particular problem that this represents in terms of protein synthesis.

Explain the relationship between genes, proteins and enzymes.

Draw out a random sequence of bases of a strand of DNA and annotate it to demonstrate the non-overlapping nature of the genetic code.

Draw out the complementary strand of DNA to the one that you have drawn and annotate to illustrate how only one strand can carry the genetic information.

Notes:

Unit 1

Molecules and cells

1.1 Molecules

Practical work to include qualitative and quantitative biochemical tests

Topic Guide

Session: _____

Check List

- ▼ Generally all these tests are qualitative, i.e. the results show whether a substance is present or not.
- ▼ They are not generally quantitative, i.e. the results do not give an accurate measure of how much of the substance is present.
- ▼ The Benedict's test for reducing sugars can be semi-quantitative in so much as the colour and amount of the precipitate found in a positive test is roughly proportional to the amount of reducing sugar present. Positive results can be compared to results from solutions of known concentration of reducing sugar.
- ▼ The same considerations apply to the iodine in potassium iodide test for starch. The colour for a positive test grading from blue-black to pale brown with decreasing amounts of starch present.
- ▼ The test for lipids is physical rather than chemical, depending on the observation of the formation of an emulsion.
- ▼ The biuret test is not a simple test for proteins but is used as such by Biologists
- ▼ These tests are commonly referred to as 'Food' tests as traditionally they are used on samples of food.

Student Activity

Notes: _____

Materials

- Practical Work Sheet:
Qualitative and quantitative tests for substances of biological importance
- Safety equipment

Procedure

Follow the detailed instructions on the Practical Work Sheet.

Set work

Write up and tabulate the results of all your tests.
Comment on any observations that you recorded that are outside of the normally expected results.

Unit 1

Molecules and cells

1.2 Enzymes

Enzymes

Topic Guide

Session: _____

Check List

- ▼ All enzymes are protein in nature, and fall into the group of 'globular' proteins with a complex 3D structure.
- ▼ Enzymes are catalysts which speed up the rate of reaction of much larger amounts of reactants without themselves being used up in the process.
- ▼ Unique amongst catalysts they are denatured by extreme conditions of pH and temperature etc.
- ▼ Their activity depends upon their complex 3D shape which creates an active site which combines with the substrate to form an enzyme/substrate complex which lowers the activation energy of reactants.
- ▼ Their complex 3D shape also accounts for enzyme specificity as the active site has a shape complementary to the shape of the substrate.
- ▼ Disruption of the 3D shape accounts for denaturation.
- ▼ pH has an effect on the 3D shape of enzymes, especially the active site which has an electric charge.
- ▼ Any effect on the active site alters the reactivity of the enzyme. There is an optimum pH, either side of which reactivity drops.
- ▼ Extremes of pH permanently disrupt the active site and thus denature the enzyme.
- ▼ Similar effects are seen with temperature, except low temperatures do not denature enzymes. The rate of enzyme catalysed reactions, like all chemical reactions, are reduced with low temperatures.
- ▼ Optimum conditions of pH and temperature vary with the particular enzyme, which reflects the conditions in which the cell exists.
- ▼ The relative amounts of enzyme and substrate affect the rate of reaction as it affects the formation of the enzyme substrate complex. Only one can be rate regulating or limiting at any one time.
- ▼ Active site-directed inhibition interferes with the active site so that combination with the substrate is prevented, e.g. competitive inhibition when a substance with a shape similar to the substrate occupies the active site.
- ▼ Non-active site-directed inhibition involves combination of a substance (often an end product) with an allosteric site, which alters the overall shape of the enzyme, and thus the active site.

Student Activity

Materials

- ☐ OHT Temperature, pH, enzyme and substrate concentration
- ☐ OHT Activation energy
- ☐ OHT Enzyme-substrate complex

Procedure

- ☐ OHT Activation energy illustrates activation energy and catalysts. Define 'enzyme'. Explain that enzymes are proteins. Use the opportunity to revise tertiary structure, stress the importance of shape.
- ☐ OHT Enzyme-substrate complex illustrates active site, enzyme-substrate complex, specificity. Define these terms.

Set work

Plot the curve for the rate of a typical chemical reaction against temperature from 0 - 100°C

On the same axes plot the rate of an enzyme catalysed reaction with an optimum temperature of 40°C.

Explain the relationship shown by the two curves.

Notes:

Unit 1

Molecules and cells

1.2 Enzymes

Enzymes

Topic Guide

Session: _____

Check List

- ▼ Enzymes have many commercial uses as a result of their catalytic properties and specificity, e.g. pectinases in food modification and proteases in biological detergents.
- ▼ The extraction of fruit juices aided by the addition of two enzymes; cellulase which weakens the cellulose cell walls, and pectinase which attacks the glue-like substance pectin which forms the middle lamella, sticking cells together.
- ▼ The resulting yield of juice is greater and purer than from the traditional practice of crushing the fruit whole, then separating the solid matter.
- ▼ A biological washing powder is one which contains digestive enzymes in addition to the normal detergent.
- ▼ Protein digesting enzymes (proteases) help break down protein stains like egg and blood. Fat digesting enzymes (lipases) deal with grease, whilst starch digesting enzymes (amylases) work on starch based food products such as gravy. The broken down products of these 'biological stains' are then easily washed out.
- ▼ Newer products with thermostable enzymes can be used in washes at 60°C or above with improved results.
- ▼ Immobilisation of commercial enzymes enables them to be reused again and again, and prevents them being lost to contaminate the end product.
- ▼ Immobilised enzymes are enzymes that have been attached to another (insoluble) material in some way and hence prevented from moving freely within the substrate mixture.
- ▼ They may be attached to a fixed membrane or gel made of a range of substances including silica, starch, cellulose. In other cases the enzyme is encapsulated within beads of another material and mixed within the substrate, and are recovered by filtering or other methods.
- ▼ Immobilised enzymes can lead to much greater production efficiency with continuous flow of reactants past the immobilised enzyme.
- ▼ Immobilised enzymes tend to be more stable and are less likely to be inactivated or denatured by high temperatures, changes in pH, or presence of other chemicals.
- ▼ Immobilised enzymes can also be used for longer before their activity decreases.
- ▼ A disadvantage of immobilising enzymes is that the rate of reaction may be slower because the enzyme has reduced kinetic energy and is often partitioned from the substrate by a membrane through which the substrate must diffuse.
- ▼ An example is immobilised lactase used to produce lactose reduced milk.

Student Activity

Materials

- Practical Work Sheet:
The action of Immobilised Lactase enzyme on Lactose in milk.
- Practical Work Sheet:
The effect of pectinase enzyme on the extraction of juice from apples.
- OHT Immobilised enzymes apparatus

Procedure

Run the experiments following the Practical Work Sheets.

Set Work

List the advantages of immobilised enzymes in commercial processes.

Unit 1

Molecules and cells

1.2 Enzymes

Enzymes

Practical work to include experiments to investigate the effects of temperature, pH, and enzyme concentration on enzyme activity.

Topic Guide

Session: _____

Check List

- ▼ The rate of enzyme catalysed reactions can be measured in relation to the disappearance of substrate, and/or the appearance of end products.
- ▼ In experiments measuring the appearance of end products, samples of the reacting substances should be tested before the start of the experiment to demonstrate their absence.
- ▼ In experiments investigating the effects of temperature all reactants should be brought to the required temperature before mixing.
- ▼ In experiments investigating the effects of pH on enzyme activity buffer solutions are used which stabilise the pH within a narrow range, to avoid any fluctuations brought about by the reaction itself.

Student Activity

Materials

- Practical Work Sheet:
The effect of temperature on the activity of the enzyme catalase

Procedure

Carry out the experiments with the guidance of the Practical Work Sheets.

Note enzyme powder is not pure protein, it is 'packed' with inert powder, which at times is contaminated with reducing sugars. So in experiments testing for the appearance of reducing sugars as end products, it is possible to get a positive Benedicts result on the enzyme powder alone.

Set Work

Write up the findings of the experiments, suggesting sources of error, and ways of improvement.

Notes

Module 1

Core Principles

1.3 Cellular Organisation

Prokaryotic cells

Topic Guide

Session: _____

Check List

- ▼ Prokaryotic cells (bacteria) lack a true nucleus and membrane bound organelles.
- ▼ *Escherichia coli* (*E. coli*) is a bacterium found in the large intestine of animals, normally it is harmless but can cause disease under certain circumstances; new mutations can be fatal.
- ▼ The DNA is located in a central strand (bacterial chromosome), and as circular plasmids in the rest of the cytoplasm.
- ▼ The plasmids can be exchanged between bacteria, a fact exploited by genetic engineering
- ▼ The cell wall is not cellulose as in plant cells, but is formed from a mixture of polysaccharides and amino acids called murein.
- ▼ The cell surface (plasma) membrane is partially permeable and controls the transport of substances into and out of the cell.
- ▼ The cell wall provides protection and support, preventing bursting (lysis) of the cell in more dilute solutions.
- ▼ Many disease causing (pathogenic) bacteria have a slime capsule covering the cell wall which helps in protection against the body defences of the infected organism.
- ▼ Respiration is located in mesosomes which are infoldings of the cell surface membrane, sharing the principle of increased surface area of membranes with true mitochondria.
- ▼ Ribosomes are present in both prokaryotes and eukaryotes.
- ▼ Glycogen granules and lipid droplets act as energy stores.
- ▼ Flagella provide bacteria with mobility.

Student Activity

Materials

- Microscope
- Slides of bacteria, and of squamous epithelium
- OHT Structure of bacterium

Procedure

Observe the prepared slides of bacteria, and calculate the size, either by approximation or the use of the stage micrometer and eye piece graticule.

Observe □ OHT Structure of bacterium and estimate the magnification needed to reveal such detail.

Make a drawing of the squamous epithelium cells and then draw the bacteria as seen down the light microscope ON the drawing of the squamous epithelium cells

Comment on their relative sizes and relate this to the fact that many bacteria are disease causing.

Set work

Explain the relationship between the structure of an individual bacterium and the type of colony that they form.

Notes:

Session:

▼ A mesophyll cell from a leaf could be considered as a 'typical' plant cell.

- ▼ In addition the typical plant cell can be seen to possess a cell wall around the cell surface membrane, a large central vacuole surrounded by the tonoplast membrane, and chloroplasts.

Write a brief justification of 'interpretation' in Biological drawing, e.g. drawing the plant cell wall as a double line (which is not actually seen down the typical lab microscope).

Notes:

Module 1**Core Principles****1.3 Cellular Organisation****Eukaryotic cells****Topic Guide**

Session: _____

Check List

- ▼ If the specimen can be observed with the naked eye without the need for magnification the calculation of the linear magnification of any drawing of it is straightforward - being the number of times any linear dimension of the drawing is greater than that of the specimen.
- ▼ Magnifications of images of slides of biological material are given in terms of the magnification of the microscope image, that is by multiplying the power of the two lenses.e.g. $10 \times 10 = 100$.
- ▼ However reproductions of the image as seen down a microscope introduce another layer of magnification which is often overlooked.
- ▼ To calculate the linear magnification of drawings of microscope images of specimens it is necessary to know how many times the drawing is larger than the actual specimen.
- ▼ The actual size of the specimen is measured with an eye piece graticule and stage micrometer.
- ▼ Resolution is the ability to see detail.
- ▼ The higher the resolution the more of the detail present can be seen.
- ▼ Increasing magnification only reveals extra detail if the detail can be resolved.
- ▼ Resolving power of light microscope limited by the wavelength of light.
- ▼ Put simply some detail is so small that it cannot be 'hit' by light, and therefore cannot be seen.
- ▼ Endless magnification of the image produced by a light microscope yields no extra information.
- ▼ Wavelengths of electron beams are much shorter than that of light and give the electron microscope much greater resolving power than the light microscope.
- ▼ Therefore extra magnification up to $\times 250\,000$ yields an equivalent amount of detail.

Student Activity**Materials**

- Microscope
- Prepared slide of TS dicotyledonous leaf
- Practical Work Sheet:
Use of a suitable graticule to make measurements and understand the concept of scale in relation to drawings done from specimens seen using the light microscope.
- OHT Magnification and Resolution.

Procedure

Set up slide of TS Leaf mesophyll on high power

Although this may be the first sight of TS dicotyledonous leaf, it can clearly be seen to be made up of cells.

Even under the highest power ($\times 400$) very little detail will be seen within the cells.

Measure some microscopic structure using the eyepiece graticule.

Observe newspaper photographs under the light microscope using reflected light, with increasing magnifications.

Measure the size (diameter) of a mitochondrion on the electron micrograph and calculate the actual size by dividing by the magnification.

Set work

1. Distinguish between the terms "magnification" and "resolution"
2. Why can more detail be seen using a beam of electrons than using visible light?
3. Try to work out why microscopic animals appear to move so fast when seen moving under the microscope., when the actual speed can be about 10 m per hour.

Module 1**Core Principles****1.3 Cellular Organisation****Eukaryotic cells****Topic Guide**

Session: _____

Check List

- ▼ The nucleus contains the genetic material (DNA) and can be considered as the control centre of the cell.
- ▼ Within the nucleus is the nucleolus which is the centre of mRNA and ribosome synthesis.
- ▼ Rough or granular endoplasmic reticulum is a system of flat sac-like cisternae and interconnecting tubes, which acts as an intracellular transport and storage system.
- ▼ Ribosomes attached to the RER are centres of protein synthesis.
- ▼ The rough and smooth endoplasmic reticula are not related in structure or function, and are not joined. Typically there is less smooth endoplasmic reticulum in plant cells.
- ▼ The smooth endoplasmic reticulum has a wide variety of functions including fat metabolism.
- ▼ The Golgi apparatus processes proteins from the RER e.g. forming glycoproteins, which are subsequently released from the cell by exocytosis.
- ▼ Lysosomes cannot be identified solely on appearance, the activity of digestive enzymes must be demonstrated by other means.
- ▼ Mitochondria are rod-shaped organelles but appear oval in cross section. Chloroplasts are oval in structure and appear oval in cross section.
- ▼ Chloroplasts have a double membrane, and an internal thylakoid membrane system which provides a large surface area for the attachment of the pigments and enzymes of the light-dependent stage of photosynthesis. Enzymes controlling the non-light dependent stage are found in the matrix.
- ▼ Centrioles are involved in the movement of chromosomes in nuclear division, but controversy surrounds the identification of centrioles in plant cells.
- ▼ Microtubules of protein form a cytoskeleton.
- ▼ The cellulose cell wall of plant cells is fully permeable to the passage of substances, and protects and supports the cell contents, particularly via its effects on turgidity.
- ▼ The cell surface membrane has a fluid mosaic structure based on a phospholipid bilayer stabilised with cholesterol, with surface and internal proteins.
- ▼ It is partially permeable to the passage of solutes, controlling the transport of substances into and out of the cell. The surface proteins and glycoproteins act as recognition sites for antibodies and hormones.

Student Activity**Materials**

- A selection of electronmicrographs showing whole cells or parts of cells, both animal and plant.
- T.E.M. image of a whole cell (unlabelled, for homework).

Procedure

Look at the junction between adjacent cells. Is there a cell wall? Any large spaces? Look to identify the larger things first, e.g. nucleus, mitochondria, chloroplasts.

Discuss clues which point to particular functions e.g. lots of mitochondria, cilia, microvilli etc.

Set work

Label the T.E.M. of an animal cell before the next lesson.

Notes

Module 1**Core Principles****1.3 Cellular Organisation****Transport across membranes****Topic Guide**

Session: _____

Check List

- ▼ The cell surface membrane acts as a partially permeable membrane regulating the transport of substances across the membrane.
- ▼ Passive diffusion occurs across membranes down diffusion gradients from high concentration to low concentration. Fat soluble substances diffuse faster than non-fat soluble substances which must pass through the aqueous pores.
- ▼ The speed of these diffusing particles is only increased by an increase in temperature, which increases their kinetic energy.
- ▼ In addition to the effect of temperature on diffusion, the amount of a substance that diffuses in a given time (rate of diffusion) is dependent upon the difference in its concentration in two separated regions (the concentration gradient), the surface area of the separating boundary or exchange surface, and the distance separating them i.e. the thickness of the exchange surface.
- ▼ Facilitated diffusion is diffusion via special carriers which ease the passage of substances through the membrane.
- ▼ Water always moves across the cell surface membrane passively by osmosis.
- ▼ Osmosis is the special case of the diffusion of water from regions of higher water potential to regions of lower water potential across a partially permeable membrane which is more permeable to water than to dissolved solutes. (If the membrane was fully permeable the solutes would diffuse down their diffusion gradient and the water would not move.
- ▼ At room temperature and pressure pure water has the highest water potential which is given the value of zero. Solutions have a water potential of less than zero (negative).
- ▼ Increasing pressure increases the water potential and it can become positive, in other words water can be 'squeezed' out of solutions through partially permeable membranes into pure water.
- ▼ Active transport involves energy in the form of ATP from respiration to pump ions across the cell surface membrane via carriers against their diffusion gradient.
- ▼ Mass or bulk transport of fluids into and out of the cell is achieved by vacuoles fusing with, or being pinched off from, the cell surface membrane respectively.

Student Activity**Materials**

- Range of plant material
- Molar sucrose solution
- Methylene blue

Procedure

Investigate the water potential of a range of plant material: potato chips, beetroot (which allows for a check on any losses from damaged cells), onion rings, banana slices of different ripeness.

An alternative approach is to investigate any alterations of density of bathing solution by colouring with methylene blue and releasing a drop of this carefully at mid-depth into a beaker of the

original solution, if water has entered the cells by osmosis the bathing solution will have become more concentrated, and will sink when introduced into original solution. If the bathing solution has gained water from the cells it will be less dense than the original and rise when introduced into the original.

Osmosis and diffusion can be studied in the same investigation if solutions of urea are used. Initially plant material loses water to concentrated urea solution and shrinks and loses mass, but after a period urea diffuses into the plant material which recovers size and mass. A puzzling and interesting phenomenon to observe.

Set Work

Write a paragraph explaining osmosis in terms of the diffusion of water.

Module 1**Core Principles****1.3 Cellular Organisation**

Aggregations of cells

Topic Guide

Session: _____

Check List

- ▼ The cells of multicellular organisms may differentiate and become adapted for specific functions.
- ▼ In multicellular organisms cells are organised into tissues. A tissue being an aggregation of cells of common origin, structure and function.
- ▼ An example of a tissue in flowering plants is the palisade mesophyll found under the upper surface of the leaf.
- ▼ Other tissues in the leaf include spongy mesophyll, epidermis, water transporting xylem and sugar transporting phloem.
- ▼ The leaf palisade mesophyll cell is specialised for the purpose of photosynthesis. It contains numerous chloroplasts which, if living cells are observed, can be seen moving within the cytoplasm to positions favouring optimum light absorption.
- ▼ Different tissues become 'organised' into organs specialised to particular functions, e.g. the leaf is an organ of photosynthesis, and the liver is an organ of metabolic homeostasis.

Student Activity**Materials**

- Microscope
- Slides of T.S. Leaf and T.S. liver
- OHT leaf

Procedure

Examine the slides of the animal and plant tissues, and make annotated drawings relating structure to function.

Note that the liver as an organ has very little visible internal structure. The 'classic' liver lobule is most clearly seen in the pig liver.

Calculate the linear magnification of your drawings.

Set Work

List as many tissues and organs in the human body as you can.

Notes: _____

Module 1

Core Principles

1.4 The cell cycle

Chromosome structure

Mitosis

Topic Guide

Session:

Check List

- ▼ Chromosomes consist of DNA and histones (protein only found in the nucleus) in the nucleus of eukaryotic cells.
- ▼ Chromosomes only form just prior to nuclear division, either mitosis or meiosis.
- ▼ Before their formation the DNA has replicated in the S phase of interphase, replication is semi-conservative and controlled by enzymes e.g. DNA polymerase.
- ▼ Leaf palisade cells and liver cells have a diploid chromosome number and have been produced by nuclear division followed by differentiation. Differentiation limits further division.
- ▼ Chromosomes consist of a kinetochore (centromere) which is the centre of chromosome movement, and two arms of variable length depending on the position of the centromere.
- ▼ Telomeres are found at the end of the arms of chromosomes.
- ▼ When stained and viewed under UV light a characteristic pattern of light and dark banding can be seen to be unique to each chromosome of a haploid set.
- ▼ In prophase of mitosis the chromosomes form from the chromatin of the nucleus and appear as double structures made of two chromatids.
- ▼ In metaphase they align on the equator of the nuclear spindle apparatus (NSA) formed from the nuclear membrane.
- ▼ In anaphase the kinetochore divides and the chromatids separate to the poles of the NSA under the control of the centrioles.
- ▼ In telophase each of the two sets of separated chromatids (now considered as new chromosomes) become surrounded by nuclear membranes and disperse as chromatin in the new daughter nuclei.
- ▼ A new cell forms around each of the two daughter nuclei.

Student Activity

Materials

- Microscopes
- Slides of root tip squashes
- Student handouts: photocopies of OHT
- OHT Root tip squash
- OHT Normal Human Karyotype

Procedure

Examine the slides of mitosis and sketch and annotate the stages that you see.

Count the cells that you can see in each stage as an approximation of the length of each stage.

Set Work

List as many sites of mitosis in plants and animals that you can.

Notes

Module 1**Core Principles****1.4 The cell cycle****Mitosis****Topic Guide**

Session: _____

Check List

- ▼ Mitosis is nuclear division in which the daughter nuclei have the same chromosome number as the parent nucleus, typically diploid nuclei producing diploid daughter nuclei.
- ▼ The daughter nuclei are therefore genetically identical to the nucleus of the cell that produced them (except for any mutations that may occur).
- ▼ As a result of mitosis in the growth of an organism from the fertilised egg all cells therefore are genetically identical.
- ▼ The production of genetically identical cells with the full set of genetic information allows the replacement of any cells in repair processes.
- ▼ Mitotic cell division is seen in growth, repair and asexual reproduction.
- ▼ The production of new individuals involves the transfer of genetic information from parent to offspring.
- ▼ Mitosis results in cells identical to the fertilised egg reaching the reproductive organs.
- ▼ Mitosis results in all offspring of asexual reproduction being genetically, lacking genetic variation.
- ▼ In the asexual reproduction of organisms it allows for the rapid exploitation of optimum conditions where any variation would be disadvantageous.

Student Activity**Materials**

- Practical Work Sheet:

Preparation of an onion root tip squash to demonstrate stages in mitosis using a light microscope

Procedure

Prepare slides of root tip squashes.

Use □ OHT Root tip squash for guidance.

Make drawings of prophase, metaphase, anaphase and telophase nuclei.

Set work

Explain why root tips are squashed rather than sectioned when preparing slides of mitosis.

Notes: _____

Module 1**Core Principles****1.4 The cell cycle****Mitosis****Topic Guide**

Session: _____

Check List

- ▼ Clones are genetically identical organisms.
- ▼ Cloning may occur naturally, for example, identical twins in humans, binary fission in microorganisms and vegetative reproduction in plants, but it can also be achieved artificially.
- ▼ The production of crops by vegetative propagation e.g. in which cuttings are taken from a desirable original is a form of cloning, some common crop plants, for example the banana, can only be grown by cloning.
- ▼ Since members of a clone are genetically uniform under optimum conditions, they grow to the same height, flower at the same time, and produce fruit of a similar size, features which make them highly suitable for mechanised farming.
- ▼ The uniformity which makes them so attractive to farmers applies also to their susceptibility to pests, diseases and other environmental hazards. An entire crop may be wiped out by a single type of pathogen.
- ▼ It is now possible to clone plants from cell cultures through the techniques of micropropagation. In some cases, whole new plants can be propagated from single cells.
- ▼ This is useful in producing virus free stock from apical meristem cells which viruses do not penetrate.
- ▼ The cloning of animals is possible by new techniques for manipulating embryonic cells, e.g. by splitting apart the cells of developing embryos at a very early stage after fertilisation.

Student Activity

Notes:

Materials

- Samples of material illustrating vegetative reproduction by plants.

Procedure

Examine the plant material to illustrate vegetative reproduction and make annotated sketches.

Set Work

Write a paragraph explaining the role of mitosis in cloning.

Topic Guide



2B.1 Exchanges with the Environment

2B.2 Transport Systems

2B.3 Adaptations to the Environment

2B.4 Sexual Reproduction

Unit 2B

Exchange, transport and reproduction

2B.1 Exchanges with the environment

Exchange processes

Gas exchange in protozoa

Topic Guide

Session: _____

Check List

- ▼ Living organisms need to take up nutrients, exchange respiratory gases, which includes an element of excretion in the elimination of carbon dioxide, and eliminate other excretory products.
- ▼ Surface area increases with increasing size but the surface area to volume ratio decreases.
- ▼ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ▼ SA/V increased by flattened body shapes and subdivided structures e.g. exchange surfaces which aid passive and active transport.
- ▼ Exchange surfaces have other special features which aid passive and active transport in addition to their large surface area. They are thin, well supplied with blood vessels, and exposed to the external environment.
- ▼ Gas exchange surfaces must be ventilated to continually replace the external medium in order to maintain the diffusion gradients between it and the blood.
- ▼ Protozoa are single celled organisms with a large SA/V ratio, which is sufficient for gas exchange and internal transport to be by diffusion. Oxygen is absorbed and carbon dioxide eliminated.

Student Activity

Materials

- 3 pieces of paper per student sized A4, A5 and A6
- Adhesive tape and scissors.
- OHT Cubes 2cm and 1cm sides

Procedure

Make three cylindrical 'animals' from the different sized pieces of paper. Roll the paper in each case taping the short ends together to make three 'animals' of similar shape and different size. Now calculate the surface area to volume ratio, making out a table like this:

Surface area (mm ²)	volume of cylinder ($\pi r^2 \times \text{length}$)	surface area / volume (mm ³)

What trend can you recognise? Untape the A4 paper and roll it up lengthwise so that it makes a longer, thinner 'animal'. Calculate the surface area/ volume ratio of this and compare it to that of the other A4 'animal'. What is the difference? Why is there a difference?

Make up two sets of jelly cubes of different size but from the same volume of jelly with a soluble dye (methylene blue). Wash well, place in water, and observe release of dye. Relate your observations to surface area/volume ratio considerations.

Now relate all this to the question of obtaining nutrients and oxygen in solution, getting rid of soluble waste etc. i.e. exchanging materials with the outside environment (assume it's an aquatic 'animal'). You should come to see that the smaller the surface area/volume ratio, the greater the need for a transport system.

What factors other than size affect the need for a transport system? Consider the importance of shape (see results of the A4 cylinders) and the level of activity, i.e. the rate of exchange needed.

Set work

Write 10 lines on 'Specialised exchange surfaces in the human body'.

Unit 2B

Exchange, transport and reproduction

2B.1 Exchanges with the environment

Gas exchange in flowering plants

Topic Guide

Session:

Check List

- ▼ Leaves of typical mesophyte plants (those not specialised for extreme environments) have a broad thin lamina which has a large A/V, supported by a mid rib and veins of vascular tissue containing strong lignified xylem tissue.
- ▼ Internally the mesophyll tissue, mainly the spongy and to a lesser extent the palisade, has extensive intercellular spaces which link together and to the sub-stomatal cavities.
- ▼ Oxygen and carbon dioxide are exchanged by diffusion at the moist surfaces of the mesophyll cells.
- ▼ The sub-stomatal cavity exchanges gases with the external air via the stomata.
- ▼ Stomata typically open in the light and close in the dark.
- ▼ Stomata open when the guard cells are turgid and close when they are flaccid. Turgidity is achieved by the active uptake of potassium ions in the light which lowers the water potential below that of the surrounding cells
- ▼ Gas exchange is achieved by diffusion, aided by mass flow movements as a result of air currents and leaf movements.
- ▼ In the light the net movement is the absorption of carbon dioxide for photosynthesis and the release of oxygen and water vapour.

Student Activity

Materials

- Microscopes and slides of T.S. leaf
- Selection of mesophyte leaves
- OHT leaf structure

Procedure

Examine the selection of mesophyte leaves and the slides of T.S. leaf and use □ OHT leaf structure to illustrate the principle of the large surface area for gas exchange

Set Work

Make annotated sketches to illustrate the tidal (in and out) flow of gases in the leaf.

NC 65

Unit 2B

Exchange, transport and reproduction

2B.1 Exchanges with the environment

Gas exchange in humans

Topic Guide

Session:

Check List

- ### Check List
- ▼ Gas exchange occurs over large surface area of alveoli which is a product of their relatively small size and large number.
 - ▼ Diffusion gradients of oxygen and carbon dioxide dependent upon partial pressures of gases on either side of diffusion surface.
 - ▼ Diffusion surface composed of thin squamous epithelium ridged around the sandwiched capillaries, which further increases their surface area.
 - ▼ Air in alveoli remains fairly constant in composition independent of breathing cycle.
 - ▼ Surface water an inevitable consequence of a permeable surface exposed to air decreases diffusion of oxygen more than the diffusion of carbon dioxide.
 - ▼ Diffusion gradients maintained by circulating blood and ventilation of lungs.
 - ▼ As demand for oxygen increases so does steepness of diffusion gradients and speed of circulation thus meeting extra demand.

Student Activity

Materials

- Microscopes
- Slides TS alveoli
- OHT Diagram of alveoli and associated capillaries

Procedure

- ☐ Use OHT showing the structure of alveoli and associated capillaries to help interpretation of microscope slide of TS alveoli.

Estimate the diameter of one alveolus, either by using an eye piece graticule, or by 'guesstimating' in relation to the size of a red blood cell (6 - 8 μm) in one of the capillaries.

Set Work

In the disease emphysema the alveoli run together to form larger air sacs. Explain the effect this has on the surface area of the lung for gas exchange, illustrating your answer with simple diagrams and calculations.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.1 Exchanges with the environment

Digestion and absorption

Topic Guide

Session: _____

Check List

- ▼ The main regions of the gut are, the mouth (buccal cavity), oesophagus, stomach, duodenum, ileum, colon, and rectum.
- ▼ From the oesophagus to the rectum the wall of the gut is comprised of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa. These layers are modified in each region in accordance with its function.
- ▼ The oesophagus is lined with stratified epithelium. This is several layers of cells thick and protects underlying structures from damage. Mucous glands secrete mucus to lubricate the food, and thick layer of smooth muscle pushes food down by peristalsis.
- ▼ The stomach wall is folded and contains gastric glands which open into gastric pits. There are three types of secretory cells in these glands: mucus secreting cells, oxyntic cells secreting hydrochloric acid and chief cells secreting pepsinogen (later converted to the pepsin). Smooth muscle mixes and moves food into the small intestine
- ▼ The small intestine submucosa and mucosa form folds and villi which increase the surface area for the absorption of food and slow the movement of food.
- ▼ Goblet cells secrete mucus whilst Paneth cells found in the crypts of Lieberkuhn between the villi secrete antibacterial lysosome.
- ▼ Each villus contains blood capillaries to absorb all nutrients, and a lymphatic capillary (the lacteal) to absorb fats. The cells of the villus bear surface projections called microvilli.
- ▼ Brunners glands are restricted to the duodenum and secrete mucus and an alkaline fluid to neutralise the acid chyme.
- ▼ The large intestine consists of the colon where most water is absorbed, the caecum and appendix which are much reduced (vestigial) in humans, and the rectum into which faeces move before defaecation.
- ▼ Food is masticated by the teeth and the tongue to increase the surface area for digestion and to mix it with saliva for ease of swallowing.
- ▼ The smooth muscle moves the food through the gut by autonomic waves of contractions (peristalsis).
- ▼ Carbohydrates are digested by carbohydrase enzymes e.g. amylase in the saliva in the mouth, and pancreatic juice digests starch to maltose; on the membranes of the epithelium cells of the ileum maltase digests maltose to glucose; sucrase digests sucrose to glucose and fructose; and lactase digests lactose to glucose and galactose.

Student Activity

Materials

- Model of human skull for dentition.

□ OHT Human gut

Procedure

Make an annotated sketch of the human gut in relation to digestion and absorption.

Set Work

Make a table of the main differences in the structure of the wall in the oesophagus, stomach, duodenum and ileum.

Notes: _____

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in flowering plants

Topic Guide

Session: _____

Check List

- ▼ Surface area increases with increasing size but the surface area to volume ratio decreases.
- ▼ SA/V increased by flattened body shapes and structures.
- ▼ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ▼ Discussions of development of transport systems also involve level of complexity of organism.
- ▼ Development of transport systems involve the mass flow of fluids.
- ▼ Development of transport systems involve development of specialised exchange surfaces with large surface areas.
- ▼ Diffusion still important in all exchanges, but not in transport throughout volume of organism.
- ▼ Xylem tissue is composed of vessels, tracheids, fibres and xylem parenchyma.
- ▼ Vessels have lignified walls with pits, empty lumen, reduction of cross walls, diameters range from 20 - 600 μm , and they can be up to a metre long.
- ▼ These elongated empty elements are well adapted to the rapid transport of water, offering little resistance to flow of water in transpiration stream.
- ▼ Xylem tracheids are very similar to vessels except they have pitted cross walls at regular intervals, and they are smaller in cross section. They are also used in the transport of water.
- ▼ Fibres are elongated narrow lignified elements for support.
- ▼ Xylem parenchyma are living cells which occur in the medullary rays and act as food storage regions.
- ▼ Phloem tissue is composed of sieve tube elements, companion cells, phloem fibres and phloem parenchyma.
- ▼ Sieve tube element have cellulose cell walls, sieve tube plates at regular intervals, and living contents but no nuclei. They are involved in the transport of organic compounds, mainly sucrose.
- ▼ The companion cells do have nuclei and play some role in the functioning of the sieve tube elements.
- ▼ Phloem fibres and phloem parenchyma are found associated with the sieve tubes and companion cells in the vascular bundle.

Student Activity

Materials

- Microscopes
- Matches teased and stained in phloroglucinol and HCl
- OHT Summary of structure of vessels in xylem
- OHT Summary of structure of sieve tube elements and companion cells in phloem

Procedure

Observe teased matches stained in phloroglucinol and HCl which stains lignin red, for good 3D view of xylem elements. Good reminder of role of xylem as wood in everyday life.

Position of phloem outside the expanding cylinder of xylem, and its unthickened cellulose cell walls, mean that secondary phloem is continually being stretched and destroyed in woody parts, forming a narrow layer just under the bark, and does not accumulate like the xylem.

Set work

Explain in terms of the movement of water through the plant why vessels with a larger cross section are mainly produced in the Spring in temperate climates like ours.

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Movement of water

Topic Guide

Session: _____

Check List

- ▼ Roots provide anchorage, and take up water and inorganic ions from the soil solution.
- ▼ As roots have to resist predominately pulling strains, the vascular (transport) tissue containing the phloem and woody xylem is found in the centre.
- ▼ Uptake of water and ions from the soil solution is via the root hairs which present a large total surface area for uptake.
- ▼ Root hairs are found just behind the actively growing root tips of young roots.
- ▼ The endodermis is a cylinder surrounding the central vascular tissue, it is composed of cells the walls of which become impregnated with impermeable waterproof suberin and eventually die, except for living passage cells next to the points of the central 'star' of xylem tissue.
- ▼ Water can enter and travel through the root along three pathways; the apoplast, symplast and vacuolar pathways.
- ▼ The endodermis acts as a barrier to prevent the loss of accumulated ions in the root, and to force the water and ions being taken up to pass through the contents of living cells at least once in its passage across the root.
- ▼ The apoplast pathway is in the porous cellulose cell walls, and the water is pulled directly through by the transpiration stream, and it only passes through a living membrane in the passage cells of the endodermis.
- ▼ The symplast pathway involves water entering into the cytoplasm of a root hair cell and passing in the cytoplasm from cell to cell down a water potential gradient via the plasmodesmata.
- ▼ The vacuolar pathway involves water passing down a water potential gradient from vacuole to vacuole, the pathway of greatest resistance.

Student Activity

Notes:

Materials

- Washed roots of seedlings and potted plants
- Microscope and slides of T.S. root tip region

Procedure

Examine the washed roots, snip off the young tips, mount in water and sketch the root hairs.

Examine the slides of T.S. root tip region and make low power plans of the distribution of tissues

Set Work

Write a paragraph on how roots are adapted to their function.

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Movement of water

Topic Guide

Session: _____

Check List

- ▼ The xylem vessels are adapted to the mass transport of water.
- ▼ The lignified walls are waterproof, avoiding absorption and keeping water in the lumen.
- ▼ They are strong to withstand huge negative pressures 'suction' generated by the transpiration stream as the water column is pulled up by cohesion (there is a measurable decrease in diameter of tree trunks under conditions of high transpiration).
- ▼ The smooth lignified walls also offer good adhesion for the water, thus supporting the water column as it moves up the plant.
- ▼ Pits in the walls allow for a continuous system of water to by-pass any air bubbles and breaks in the columns of water, as a result of columns of water breaking under tension or wind movements, or freezing forcing air out of solution in the xylem.
- ▼ Root hairs actively take up inorganic ions and water follows passively down a water potential gradient generating a root pressure.
- ▼ Root pressure can only account for a rise of a few metres but could be important before leaves are fully open in the spring in temperate climates.
- ▼ Once in xylem capillarity aids rise but main force is generated by transpiration at the leaves.
- ▼ Transpiration from the leaves generates the major force for the upward movement of water in the transpiration stream.
- ▼ Water evaporates from the surfaces of the mesophyll tissue in the leaves, and the water vapour diffuses out of open stomata.
- ▼ Stomata have to strike a balance between opening for carbon dioxide uptake and closing to control loss of water vapour.
- ▼ Any factor that increases the water potential gradient between the leaf and the atmosphere will increase the rate of transpiration, e.g. dry air, moving air, and increase in temperature.
- ▼ The evaporation of water in the leaves generates an upward pull on the water in the xylem vessels and tracheids, creating the transpiration stream.

Student Activity

Materials

- Various non-'hairy' leaves
- Microscopes
- Slides of TS leaf showing stomata
- Glass slides and coverslips
- Small 'pots' to stand on an electronic balance.
- Potometer demonstration
- Practical Work Sheet:
The use of the potometer
- Practical Work Sheet 10: Stomatal counts

Procedure

Paint the various surfaces of the leaves with clear nail varnish, allow to dry, peel off dry film, and mount in water on a clean slide under a cover slip.

Observe impressions of stomata and count/estimate the number visible on a variety of leaves under x100.

Observe the TS of the leaf for views of the stomata in section.

Place a pot of water on a digital balance and record the loss of mass by evaporation under normal room conditions.

Repeat with fan and/or hair dryer with warm air, and try to record any differences in the rate of water loss by evaporation.

Set work

Write a paragraph on your observations of the distribution of stomata on leaves.

Record the results of the potometer experiment with your observations.

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Movement of nutrients

Topic Guide

Session: _____

Check List

- ▼ Mineral ions are taken up by the root hairs, which have a large total surface area, by diffusion and active transport. Only actively growing roots absorb substances from the soil.
- ▼ Mineral ions are transported by solvent drag in the transpiration stream from the roots to the leaves.
- ▼ However, they arrive in different proportions and at different rates, indicating that the process is not simply one of being swept up by solvent drag.
- ▼ The cylinder of active living cambium lies next to the water transporting xylem of the sap wood, and may have a role in importing and exporting ions to and from the transpiration stream.
- ▼ Translocation of assimilates (organic substances synthesised in the plant by photosynthesis) e.g. sugars, amino acids, hormones, nucleic acids etc. occurs in the phloem tissue.
- ▼ Organic materials move from an area of manufacture (source) to an area where they are used (sink). Sucrose thus moves from the leaves (sources) to actively growing and respiring regions such as the roots, flowers, and new buds (sinks).
- ▼ Phloem tissue (unlike most of the Xylem) is composed of living cells and elements.
- ▼ Mechanism of movement still not fully understood.
- ▼ Mass flow mechanism postulates high hydrostatic pressure in sources and low in sinks, which results in the mass flow of sucrose in solution from sources to sinks. Transfer cells in the leaves being responsible for moving sugars into the sieve tube elements.
- ▼ Contents are under positive pressure but there is no clear evidence of the necessary pressure gradients.
- ▼ Movement occurs in both directions, although this could be accounted for by considering the mass flow mechanism in respect to single columns of sieve tube elements within the phloem tissue as a whole.
- ▼ Movement of assimilates is stopped if the phloem is poisoned with a respiratory inhibitor, exposed to high or low temperatures i.e. translocation is an active process, only occurring in those sieve tube elements showing cytoplasmic streaming.
- ▼ Ringing removes all tissues (including the phloem) outside of the xylem, and radioactive tracers e.g. ^{32}P and ^{14}C allow the movement of materials in the xylem and phloem to be detected.
- ▼ ^{32}P supplied to the roots will pass through the ringed region, whereas ^{14}C taken up the leaves and assimilated into sucrose will accumulate above the ring.

Student Activity

Materials

- Two similar woody potted plants
- OHT Autoradiographs of ringing experiment.

Procedure

Carefully remove a 5mm ring of all the tissue external to the xylem in the stem of one of the plants.

Set both plants aside under ideal conditions for regular daily observation.

Keep a record of your observations of the plants and compare them with the diagrammatic representations of ringing experiments.

- OHT Autoradiographs of ringing experiment can be used to anticipate results

Set work

Write a paragraph explaining the origin of the sugary film found on pavements and parked cars under trees in the summer months.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in mammals

Topic Guide

Session: _____

Check List

- ▼ The functions of the circulatory system include the transport of oxygen and carbon dioxide between the lungs and the tissues of the body, metabolites to and from the gut, liver and kidneys, metabolic wastes from the liver to the kidneys, and hormones from and between the endocrine glands.
- ▼ In single circulations blood only passes through the heart once on each complete circulation of the body.
- ▼ Means that blood passes through two sets of capillaries on each circulation, respiratory surface and body tissues.
- ▼ Represents large resistance to overcome before blood returns to heart, resulting in slow flow and low pressure in veins which are typically large blood sinuses to lower resistance to flow.
- ▼ Closed systems blood almost entirely restricted to vessels: arteries, arterioles, capillaries, venules, veins.
- ▼ Tissue fluid exuded to bathe tissues directly.
- ▼ Double circulation blood passes through heart twice on each circulation.
- ▼ Pressure relatively low to lungs.
- ▼ Pressure raised for systemic circulation to body giving high pressure and fast flow.

Student Activity

Materials

- ☐ OHT Mammalian heart
- ☐ OHT Closed double circulation diagram

Procedure

Open circulation. Cells are bathed by blood, compartmentalised in large spaces and moved around by one or more pumps. Note that insects have efficient transport of oxygen gas in air direct to tissues in the air tubes or tracheae.

Closed single circulation of fish has limitation i.e. the lack of pressure to body tissues.

☐ OHT Closed double circulation. Explain the advantages of a double circulation (it only occurs in birds and mammals - the 'warm blooded' vertebrates) Relate this diagram to the structure of the heart using the ☐ OHT.

Set work

Write 10 lines on 'Why the human heart can be considered as two separate pumps.'

Notes:

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in mammals

Topic Guide

Session: _____

Check List

- ▼ External appearance of heart shows small 'flap-like' atria, coronary blood vessels, fat deposits, and major vessels entering and leaving (venae cavae, pulmonary arch, and aortic arch).
- ▼ Coronary arteries arise just above the pocket valves at the base of the pulmonary and aortic arches, and supply the cardiac muscle of the heart wall with its own blood supply. Coronary veins return the blood to the right atrium.
- ▼ Internal structure of two atria and two ventricles separated by bicuspid and tricuspid valves.
- ▼ Chordae tendinae and muscles prevent back-opening of bicuspid and tricuspid valves when ventricles contract (ventricular systole).
- ▼ Atria walls thinner than ventricle walls.
- ▼ Pocket valves at base of pulmonary artery and main aorta prevent backflow of blood into ventricles when they relax (ventricular diastole).
- ▼ Left ventricle wall thicker than right ventricle wall to pump blood around body (systemic circulation).
- ▼ Right ventricle wall thinner than left ventricle wall as only has to pump blood via pulmonary circulation around lungs, where reduced pressure prevents formation of tissue fluid in alveoli.
- ▼ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.

Student Activity

Materials

- Sheep/Pig's heart with atria and major vessels intact for demonstration dissection
- Dissection materials
- OHT Diagram of heart structure

Procedure

It is usually difficult to obtain hearts with all the major vessels in place, and frequently they also have the tops of the atria sliced off.

The biggest problem is reconciling the actual structure of the heart with the diagrams which are used to simplify and clarify the structure.

If a heart with all the vessels attached is obtainable, connecting clear flexible tubes of the appropriate diameter to the vessels enables water to be pumped through the heart simply by squeezing it.

If a range of hearts are dissected note the variation of structure that occurs.

Filling aorta with water allows examination of the pocket valves from above.

It is difficult to choose the 'best' way of dissecting the heart, and possibly more may be seen if a range of methods of opening the heart are used.

Set work

Make a simple diagram of the heart chambers and annotate it with regard to the appearance of the real heart.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in mammals

Topic Guide

Session:

Check List

- ▼ The cardiac cycle refers to the events of a complete filling and emptying of the heart.
- ▼ It is a continuous cycle, the start point of which can be taken when heart is empty and all valves shut.
- ▼ Atria fill and internal pressure rises forcing bicuspid and tricuspid valves open.
- ▼ Ventricles fill so that whole heart full.
- ▼ Atria contract (atrial systole) so that ventricles overfilled and stretched.
- ▼ Ventricles contract with a force proportional to their degree of stretch (ventricular systole).
- ▼ Blood forced up shutting bicuspid and tricuspid valves (first heart sound) and opening pocket valves as blood forced up pulmonary artery and aorta.
- ▼ Ventricles relax (ventricular diastole) blood falls back in pulmonary artery and aorta shutting pocket valves (second heart sound).

Student Activity

Materials

- Blood pressure measuring device
- Stethoscope
- OHT Graph/chart of the cardiac cycle

Procedure

Listen to heart sounds using stethoscope. Relate sounds to valve closures and stages of cardiac cycle.

Demonstrate the measurement of systolic and diastolic blood pressure (on yourself) Explain the process and significance.

Demonstrate venous blood pressure

Stand back to a wall and raise arm to level with heart. At this point veins in hand and arm should still be visible (if visible in the first place). Mark this position. Get an assistant to raise the arm until veins 'collapse' mark this new position. Note the distance (d) between the two marks in cms. Calculate the venous blood pressure from:

$$(d-10) \times 1.055 / 13.55 \times 10 = \text{answer in mm.Hg}$$

Set work

Record your pulse rate before rising each morning and just before going to bed each evening for a week, and plot as a graph of pulse rate against time.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in mammals

Topic Guide

Session: _____

Check List

- ▼ Cardiac muscle is myogenic.
- ▼ Rate modified by sinu-atrial node (pacemaker) in wall of right atrium.
- ▼ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ▼ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ▼ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from where it radiates up through the walls back to the connective tissue barrier.
- ▼ Detected by electrodes on the skin as an ECG.
- ▼ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline.
- ▼ Pressure receptors in the main veins and arteries close to the heart detect pressure changes and regulate the cardiac output by reflexes via the medulla of the brain.
- ▼ All influences on heart rate coordinate heart rate and therefore blood supply to body (cardiac output) with demands of body.

Student Activity

Materials

- ECG charts
- OHT Diagram of heart and SA node

Procedure

Observe how the nerve message is transmitted through the heart with the aid of the OHT. Annotate a copy of this OHT

Observe copies of ECG charts (in groups) and explain how they are obtained.

Relate the ECGs to the events illustrated on the OHT.

Set work

Artificial pacemakers re-establish a fixed rhythm in those suffering erratic heart beats. Explain the effect on daily activities of having an artificial pacemaker fitted.

Notes: _____

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Transport in mammals

Topic Guide

Session: _____

Check List

- ▼ Elasticity of arteries is important in smoothing flow of cardiac output.
- ▼ Finer branches and arterioles are main sites of generation of resistance to blood flow.
- ▼ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ▼ Capillaries have large total cross sectional surface areas. Therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ▼ Diameter of capillary same as red blood corpuscles thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ▼ Plasma minus proteins exuded through thin walls to bathe tissues directly.
- ▼ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ▼ Pocket valves ensure one way flow back to heart.
- ▼ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

Student Activity

Materials

- Microscopes and slides of T.S. artery and vein, and T.S. alveoli for T.S. capillaries.
- 2mm (ring) sections cut from the aorta and vena cava of a sheep/pig's heart in saline
- 40 cm length of fishing line.
- Assorted weights (10 to 100g) and hook for their suspension.
- Retort stand and 2 clamps.
- Ruler

Procedure

Make annotated sketches of T.S. artery, vein and capillaries.

Investigation into stretch and recoil of arteries and veins.

Set up a retort stand with the section of artery or vein suspended by the fishing line to a clamp. A second piece of fishing line is used to suspend different weights from the vessel. A ruler is positioned and clamped to enable any stretching of the vessel to be measured. The exercise consists of adding weights to the line. Measure the distance stretched as a 10g weight is added and record it as a percentage of the original vessel length, then take off the weight and measure how

far the vessel recoils. Record this also as a percentage of the original vessel length. Repeat, increasing the weight by 10g each time. How do the stretch and recoil properties of arteries a veins differ. Suggest a reason.

Setwork

Make a table to compare the structure and functions of arteries, veins and capillaries.

Notes: _____

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Blood and body fluids

Topic Guide

Session: _____

Check List

- ▼ Blood consists of fluid plasma with erythrocytes (red blood cells), and leucocytes (white blood cells) and blood platelets.
- ▼ Plasma composed of 10% materials in suspension and solution.
- ▼ Plasma proteins wide variety of functions and act to buffer changes in pH.
- ▼ Materials carried in solution not strictly part of the plasma.
- ▼ Red blood cells lose nucleus in development and become biconcave corpuscles of haemoglobin.
- ▼ Red blood cell volume 30-40% of total blood volume.
- ▼ Large surface area to volume ratio individually due to biconcave shape, and huge total surface area due to small size (6-8 μm) and huge numbers.
- ▼ Males higher blood count/haemoglobin than females.
- ▼ There are several types of leucocytes (neutrophils, eosinophils, monocytes and lymphocytes) and they form basis of immune system.
- ▼ Leucocytes engulf foreign particles e.g. bacteria and viruses by phagocytosis, and secrete antibodies against foreign antigens, including bacteria and viruses.
- ▼ Platelets are fragments of white cells.

Student Activity

Notes: _____

Materials

- Slide of stained blood smear.
- Practical Work Sheet:
The microscopic examination of stained blood films and the identification of cells
- OHT Blood components

Procedure

Observe slide of stained blood smear with aid of OHT showing structure and function of red cells, leucocytes and platelets.

Red blood cells are amongst the smallest things you will see in this course and the light and sub-stage condenser must be carefully adjusted otherwise it is difficult to see them.

White cells are widely scattered and typically stained blue, especially the nucleus. It may be difficult to differentiate between the different types.

Platelets may just be seen under the high power ($\times 40$) objective lens as tiny granules.

Set work

List the functions of the four types of leucocyte: neutrophils, eosinophils, monocytes and lymphocytes.

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Blood and body fluids

Topic Guide

Session:

Check List

- ▼ Reversible combination of haemoglobin and oxygen in the capillaries of the pulmonary circulation is a physical association.
- ▼ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor.
- ▼ Gas exchange at tissues is in effect the reverse of that at the lungs similarly explained in terms of diffusion gradients (partial pressure gradients).
- ▼ Bohr effect applies to conditions in tissues illustrates how conditions of increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ▼ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen. Note that the placental artery is some distance from the lungs of the mother and therefore not particularly well oxygenated.
- ▼ Myoglobin is a pigment found in red (endurance type) muscle fibres and has a greater affinity for oxygen than does haemoglobin, so that it is capable of loading up high with oxygen from relatively lower saturated haemoglobin. It acts as an intermediary between oxygen in the blood and the muscle fibres.
- ▼ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.

Student Activity

Materials

- ❑ OHT Bohr effect
- ❑ Myoglobin, fetal and adult haemoglobin dissociation curves.

Procedure

Revise structure of haemoglobin. Remember that there are four possible attachment sites for oxygen on each molecule of Hb. When all the sites on all the molecules are occupied the blood is 100% saturated.

□ OHT shows that this situation occurs in the lung alveoli. Where oxygen is being used by respiring tissues a concentration gradient develops with the result that oxygen dissociates from Hb and diffuses into the tissues. Annotate a copy of the OHT chart.

Bohr effect. Note the effect of increasing carbon dioxide on the dissociation of oxygen using the $\square$ OHT. Annotate a copy of this OHT.

Fetal haemoglobin. Note the difference between adult and fetal Hb using the $\square$ OHT.

Remember that these curves are to be looked at as 'loading' with oxygen at the lungs from left to right; and 'unloading' oxygen at the tissues from right to left.

Set work

Write a paragraph on how increased muscle activity has the effect of increasing the release of oxygen from the oxyhaemoglobin in the erythrocytes.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.2 Transport systems

Blood and body fluids

Topic Guide

Session: _____

Check List

- ▼ The hydrostatic pressure of the blood in the capillaries causes plasma minus its proteins to be forced through the thin walls of the capillaries.
- ▼ This fluid bathes all the tissues and is known as tissue fluid.
- ▼ It carries substances in solution from the blood to supply the tissues, e.g. oxygen, nutrients, hormones, antibodies etc; and drains waste products e.g. carbon dioxide away.
- ▼ Most of the tissue fluid is reabsorbed back into the capillaries as the hydrostatic pressure drops as the blood passes through the capillaries.
- ▼ Excess tissue fluid is drained away into blind ending lymphatic capillaries.
- ▼ Lymph is tissue fluid that has been drained into lymphatic capillaries, with lymphocytes added by lymph nodes which occur at intervals.
- ▼ Special lymph capillaries in the villi of the lining of the small intestine, known as lacteals, preferentially absorb and transport fats, so that lymph contains more fats than plasma.
- ▼ Eventually the lymph is returned to the general circulation in the major veins near to the heart.
- ▼ Movement of the lymph in the lymphatic system is maintained by the massaging effects of the muscles and breathing movements, and the one-way pocket valves; all features common to the veins of the circulatory system.

Student Activity

Materials

- Slide of stained blood smear.
- OHT Relationship between blood and lymph

Procedure

Use OHT to understand how tissue fluid and lymph are formed. Explain the meaning and differentiate between the terms blood, plasma, tissue fluid and lymph.

Consider the blood vessels and lymph vessels of a working muscle. Discuss what might happen to the following blood components which enter via the artery:

- a) a molecule of glucose
- b) a molecule of oxygen attached to haemoglobin
- c) a molecule of water from the plasma

Set work

Answer the following questions (max. one side of A4. no diagrams needed)

Explain how the lymphatic system helps to maintain a relatively constant blood volume.

Why is this important?

Notes:

Unit 2B

Exchange, transport and reproduction

2B.3 Adaptations to the environment

Structural adaptation

Topic Guide

Session:

Check List

- ▼ Species are adapted to survive in particular environmental conditions.
- ▼ External features of organisms are related to the physical characteristics of a specific habitat.
- ▼ Adaptations of flowering plants to extreme environments such as xeromorphic adaptations to conditions of water shortage, and hydrophytic adaptations to life in water.
- ▼ Xerophytes have a thickened waterproof cuticle which reduces water loss through the surface of the leaf, especially on the upper surface of the leaf which is most exposed to air currents and heat absorption from sunlight.
- ▼ Surface of the leaf may be 'hairy' (not true hairs) which protect the stomata from air currents.
- ▼ Stomata can be reduced in number, especially on the upper surface of the leaves, where the exposure to the heat of the sun and air currents is the greatest, indeed some e.g. laurel, have no stomata on the upper surface.
- ▼ Stomata can be sunken in pits and grooves, which protects them from air currents, e.g. on pine 'needles'.
- ▼ Leaves can have a reduced surface area, which also reduces the number of stomata, e.g. pine 'needles'; and gorse and cacti where the leaves are reduced to spines.
- ▼ Leaf folding or rolling reduces water loss through the stomata by protecting them from air currents, and enclosing them in a zone of high humidity, e.g. *Ammophila* (sand dune grass).
- ▼ Leaves can be succulent, with tissues where water can be stored for periods of drought, e.g. *Mesembryanthemum*.
- ▼ Cells of the leaves have mucilage and can withstand dehydration for longer periods than those of non-xerophytes (mesophytes).
- ▼ Leaf fall stops transpiration. Deciduous plants lose their leaves with the onset of winter in temperate regions, when the low temperatures inhibit water uptake by the roots.

Student Activity

Materials

- Assorted plants and parts of plants showing a range of xerophytic adaptations e.g. cactus with spines, succulent with fleshy leaves, pine needles, holly leaves, marram grass, plus one mesophyte e.g. *Pelargonium*.
- Microscopes and slides
- Two leaves per student (one xerophyte e.g. holly and one mesophyte, e.g. *Pelargonium*) coated on their under surface with a layer of clear nail varnish.

Procedure

Compare the numbers and distribution of stomata on a xerophytic leaf e.g. holly and a mesophytic leaf. Carefully peel off the layer of nail varnish that has been painted on to the lower leaf surfaces of the two plant types and mount a small piece on a microscope slide. Examine the imprint of the epidermal surface and identify the guard cells and stomata. Count how many stomata occur in the field of view, then repeat this count on different parts of

the slide. Record the average, then repeat using the other leaf (on the same power of magnification). Compare the numbers of stomata on the two leaves.

Note that not all of the xerophytic adaptations are limited to plants living in hot dry climates. Other important groups of plants show xerophytic (water stress) modifications e.g.

Plants which retain leaves all year round (evergreens) and must survive long frozen winters (e.g. conifers)

Plants adapted to salty environments (halophytes) e.g. salt marsh plants

Wet acid heath plants where water uptake is restricted by xerophytic modifications to avoid toxic levels of iron uptake.

Set work

Tabulate your results of stomatal counts and draw conclusions on the distribution of stomata in relation to water loss.

Unit 2B

Exchange, transport and reproduction

2B.3 Adaptations to the environment

Structural adaptation

Topic Guide

Session:

Check List

- ▼ Hydrophytes are plants adapted to life in water.
- ▼ Flowering plants are secondarily aquatic, that is they have structural adaptations to a terrestrial life, which have become modified for life in water.
- ▼ Plants which live in fresh water or inhabit the margins of rivers and lakes lack oxygen for root respiration.
- ▼ The uptake of minerals is an active process requiring energy from aerobic respiration.
- ▼ Rice is a hydrophyte. Its roots have an unusually high tolerance to ethanol produced by anaerobic respiration and its seeds can germinate in oxygen starved soils.
- ▼ In common with other water adapted plants it also develops an interconnecting system of large air spaces (aerenchyma) linking the roots with the leaves above water.
- ▼ Invertebrates show structural and physiological adaptations to the varying oxygen concentrations found in fresh water, these include external gills, direct access to air, and the presence of respiratory pigments.
- ▼ External gills are outgrowths from the body which increase the surface area for diffusion of gases between the water and the internal tissue fluids. These occur on different parts of the body in different organisms.
- ▼ Direct access to air is found in a number of insect larvae, e.g. mosquito larvae have snorkel like breathing tubes which enable them to breathe atmospheric air. This adaptation allows them to survive in relatively warm and stagnant water.
- ▼ The diving beetle has masses of fine hairs on the underside of its abdomen which trap air so that the animal has its own 'diving bell'.
- ▼ Respiratory pigments such as haemoglobin greatly increase the amount of oxygen available to body tissues, releasing it readily to respiring tissues.
- ▼ A number of crustacea, for example, crayfish and shrimps possess a blue pigment called haemocyanin with copper rather than iron forming the oxygen associating part of the protein molecule.

Student Activity

Materials

- Microscope and slides of T.S. Aerenchyma and mosquito larvae
- OHT Aerenchyma
- OHT Mosquito larvae

Procedure

Make annotated sketches of the adaptations shown by these specimens

Set Work

Write a paragraph on why warm water outflows from power stations will affect the animals found there.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.4 Sexual reproduction

Topic Guide

Session: _____

Check List

- ▼ Offspring result from the fusion of gametes, forming a zygote.
- ▼ This fusion of gametes involves various genetic mixing events and therefore leads to genetic variation in offspring.
- ▼ These genetic mixing events include events in the nuclear division (meiosis) involved in the production of gametes, and in the random fusion of gametic nuclei from different sexes.
- ▼ Meiosis is a reduction division in which the diploid number of chromosomes (two sets) is reduced to the haploid (one set).
- ▼ In the first phase of meiosis (Meiosis I) the two sets of chromosomes pair up, so that chromosomes occur in homologous pairs. Each chromosome is duplicated into two chromatids, so one pair of chromosomes is made up of four chromatids.
- ▼ The homologous chromosomes of a pair entwine, one chromatid of each pair breaks and rejoins with the broken chromatid of the other pair, in a process known as genetic recombination or crossing over.
- ▼ The chiasmata align on the equator of the nuclear spindle apparatus (NSA), before the homologous chromosomes repel each other to opposite poles.
- ▼ Cross overs are visible under the light microscope and are known as chiasmata (Greek for crosses), they result in the exchange of genes (alleles) between homologous chromosomes.
- ▼ Either chromosome of each pair can go to a particular pole, resulting in mixing of the original sets (independent assortment).
- ▼ Two daughter nuclei are thus formed, each with one (haploid) set of chromosomes, with each chromosome composed of two chromatids.
- ▼ The second phase of meiosis (Meiosis II) involves the centromeres of the chromosomes aligning on the equator of a each of two new NSA formed at right angles to the first.
- ▼ The chromatids then repel each other to form four new haploid nuclei.
- ▼ Animals and plants are typically diploid and have haploid gametes, but mosses have haploid plant bodies, produce gametes without meiosis which fuse to form a diploid sporophyte which produces haploid spores by meiosis to produce new haploid moss plants.

Student Activity

Materials

- Microscopes and slides of meiosis
- Practical Work Sheet:
Observation of slides of insect testis squash

Procedure

Examine the slides and make sketches of chiasmata.

Set Work

Make simple line diagrams to show the behaviour of chromosomes during meiosis.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.4 Sexual reproduction

Reproduction in flowering plants

Topic Guide

Session: _____

Check List

- ▼ The structure of flowers is adapted to the mode of pollination, the two main ones being insect and wind pollination.
- ▼ Pollination is the transfer of pollen from the pollen sacs of the male stamens to the stigma of the female carpel.
- ▼ Insect pollinated flowers typically have bright coloured floral parts (especially petals), nectar, and scent to attract insects.
- ▼ Petals may be modified as landing platforms for insects, stamens are designed to deposit pollen on visiting insects, and stigmas are arranged to have pollen grains deposited on them from visiting insects.
- ▼ Wind pollinated flowers have reduced floral parts, no nectar, prominent hanging stamens exposing, and large 'hairy' stigmas collecting, pollen carried on air currents.
- ▼ Wind pollinated plants typically flower before the emergence of the leaves in the spring of temperate climates.
- ▼ Various arrangements exist to reduce the possibility of pollen reaching the stigma of the same plant.
- ▼ Protandry (development of the stamens before the stigma of the carpel).
- ▼ Protogyny (development of the stigma before the stamens).
- ▼ Dioecious species with separate male and female plants.
- ▼ Pollen germinates on a compatible stigma, and the pollen tube grows down through the style, to reach the egg cell (ovum) nucleus in the ovule.
- ▼ The pollen tube nucleus degenerates, and the generative nucleus divides into two male gametic nuclei.
- ▼ One of the male gametic nuclei fuses with the ovum nucleus to form the diploid zygote nucleus, and the other fuses with the two polar nuclei to form the triploid endosperm nucleus.
- ▼ This double fertilisation is unique to flowering plants.

Student Activity

Materials

- Selection of wind and insect pollinated flowers (or pictures if not in season).
- Microscope and slides of pollen grains, T.S. pollen sacs, and T.S. ovary of flowering plant.
- Practical Work Sheet:
The factors affecting the growth of pollen grains
 - OHT Carpel with pollen tube developing
 - OHT Insect pollinated flower and wind pollinated flowers

Procedure

Examine the material and slides and relate to theory.

Carry out an experimental investigation into the factors affecting the growth of pollen grains.

Set work

Write a paragraph distinguishing between pollination and fertilisation in a flowering plant.

Notes:

Unit 2B

Exchange, transport and reproduction

2B.4 Sexual reproduction

Reproduction in humans

Topic Guide

Session: _____

Check List

- ▼ The male reproductive system consists of the testes which produce spermatozoa by meiosis.
- ▼ A system of tubes and erectile tissue transfer them to the female reproductive tract.
- ▼ Accessory glands are important in secreting substances essential for successful fertilisation of the female.
- ▼ The female system consists of ovaries which release egg cells (ova) into the abdominal cavity, from where they are swept down the oviducts by ciliated epithelium, into the uterus where they may or not be implanted.
- ▼ The uterus connects to the exterior by the vagina.
- ▼ The ova are produced (oogenesis) by meiosis in the germinal epithelium of the ovaries. Of the products of meiotic nuclear division, one accumulates all the cytoplasm to form the relatively large ovum, and the others are reduced to polar bodies.
- ▼ Spermatozoa are produced (spermatogenesis) by meiosis in the germinal epithelium of the testes. The four products of meiosis all develop into spermatozoa.
- ▼ The menstrual cycle is a monthly version of the ovarian cycle found in all mammals.
- ▼ A sequence of hormonal secretions from the brain, pituitary gland, and the ovaries themselves, coordinated by negative feedback loops control the events of the cycle.
- ▼ Luteinising hormone stimulates the release of the an ovum from an ovarian follicle, and the development of the corpus luteum. In the male it stimulates the secretion of testosterone by the testes.
- ▼ Follicle stimulating hormone initiates the development and growth of the ovarian follicles, and stimulates the ovary to secrete oestrogen. In males it stimulates spermatogenesis by the testes.
- ▼ Oestrogen stimulates the development of the primary and secondary sexual characteristics, the development of the uterus lining in the first half of the menstrual cycle.
- ▼ Progesterone stimulates the secretory phase of the uterus in the second half of the cycle, and maintains pregnancy whilst suppressing further ovulation

Student Activity

Materials

- Microscope and slides of L.S.Ovary, T.S. Testis and insect testis squash
- Supplementary Practical Work Sheet 14: Microscopic examination of the histology of ovary and testis
- OHT Menstrual cycle

Procedure

Examine the slide of T.S. Ovary and make an annotated sketch of various stages in the development of ovarian follicles.

Examine the slide of T.S. Testis and draw a plan of a seminiferous tubule, noting stages in spermatogenesis.

Examine the slide of insect testis squash to identify stages in meiosis.

Set Work

List the hormones involved in the menstrual cycle along with their respective roles.

Explain how the study of the insect testis squash is relevant to the study of reproduction in humans.

Unit 2B

Exchange, transport and reproduction

2B.4 Sexual reproduction

Reproduction in humans

Topic Guide

Session:

Check List

- ▼ Spermatozoa are ejaculated by the erect penis in the region of the cervix at the entry to the uterus.
- ▼ Peristaltic movements of the female tract and the motility of the spermatozoa themselves result in movement up the oviducts.
- ▼ If these events coincide with the release of one or more ova, fertilisation can occur high up in the oviduct.
- ▼ The fertilised egg immediately enters into mitotic cell division, and is a hollow ball of cells (blastocyst) by the time the uterus is reached.
- ▼ The blastocyst becomes implanted in the pre-prepared lining of the uterus, and secretes gonadotrophic hormone.
- ▼ The lining of the uterus is maintained and the menstrual cycle is suspended.
- ▼ The placenta develops and secretes progesterone which helps to maintain the pregnancy and suppress further ovulation.
- ▼ The placenta attaches the fetus to the uterine wall and has a large surface area for the exchange of materials with the maternal circulation, e.g. the absorption of oxygen and nutrients, and the elimination of waste products, e.g. urea and carbon dioxide.
- ▼ The efficiency of exchanges is increased by extensive breakdown of tissue in the placenta and the uterus wall, reducing the diffusion distance between the two circulations.
- ▼ At full term the fluid filled amnion which surrounds the fetus bursts, the fluid lubricates the system and birth is initiated.
- ▼ The hormone oxytocin secreted by the posterior pituitary lobe produces powerful contractions of the uterus, induces lactation, and stimulates the ejection of milk during suckling.
- ▼ The hormone prolactin secreted by the anterior pituitary lobe stimulates lactation.

Student Activity

Materials

- Microscope and slides of spermatozoa
- OHT Structure of male/female reproductive organs

Procedure

Review the topic with the aid of the material provided.

Set Work

List the reasons why the fetal and maternal circulations should not mix.

Notes:

Topic Guide



2H.1 Exchanges with the environment

2H.2 Transport of materials

2H.3 Human ecology

2H.4 Human reproduction and development

Unit 2H

Exchange, transport and reproduction in humans

2H.1 Exchanges with the environment

Breathing

Topic Guide

Session: _____

Check List

- ▼ The thorax is defined by the rib cage and its associated intercostal muscles, and the diaphragm.
- ▼ A system of air tubes; the trachea, bronchi and bronchioles form the 'bronchial tree' supplying the air sacs (alveoli) of the lungs
- ▼ Inspiration occurs when the intercostal muscles contract raising the rib cage, and the diaphragm contracts and flattens, increasing the volume and decreasing the pressure within the thorax below that of the external air pressure, resulting in the entry of air.
- ▼ Expiration at rest is passive, as the intercostal muscles and the diaphragm relax and the tissues of the thorax recoil as a result of their elasticity.
- ▼ The pleural fluid between the two pleural membranes lubricate the movement, and keep the lungs inflated against the wall of the thorax. Surfactants secreted inside the alveoli lower their surface tension and decrease their risk of collapse.
- ▼ The volume of air that is breathed during a complete breathing cycle of one breath in and one out is known as the tidal volume. Breathing becomes deeper as well as more rapid with exercise, and expiration becomes active.
- ▼ The vital capacity is the total amount of air that can be breathed with the deepest possible breath in and the deepest possible breath out.
- ▼ Breathing volumes can be measured with a simple spirometer. The principle involves a floating air (or oxygen) filled chamber which rises when the subject is breathing out and falls when the subject is breathing in. If the recording pen is attached directly to the chamber the recorded trace shows the movement of the chamber, if it is attached via a system of pulleys then the trace can be inverted.

Student Activity

Materials

- Practical Work Sheet:
The estimation of vital capacity using simple apparatus
- Practical Work Sheet:
The use of the spirometer (Spirometry)
- Spirometer traces for interpretation.
- OHT Spirometer traces

Procedure

Set up a simple spirometer as a demonstration.
Note the principles and the problems.

Set work

Write up the results and conclusions of the investigations. Note problems, sources of error, and suggestions for improvements.

Notes:

2H.1 Exchanges with the environment

Topic Guide

Session:

- ▼ The increased rate and volume of breathing maintains the diffusion gradients across the walls of the alveoli.

Notes:

Unit 2H

Exchange, transport and reproduction in humans

2H.1 Exchanges with the environment

Digestion and absorption

Topic Guide

Session: _____

Check List

- ▼ The main regions of the gut are, the mouth (buccal cavity), oesophagus, stomach, duodenum, ileum, colon, and rectum.
- ▼ From the oesophagus to the rectum the wall of the gut is comprised of four layers: the innermost mucosa, submucosa, muscularis externa and outermost serosa. These layers are modified in each region in accordance with its function.
- ▼ Food is masticated by the teeth and the tongue to increase the surface area for digestion and to mix it with saliva for ease of swallowing.
- ▼ The oesophagus is lined with stratified epithelium, which protects underlying structures from damage. Mucous glands secrete mucus to lubricate the food, and thick layer of smooth muscle pushes food down by peristalsis.
- ▼ The stomach wall is folded and contains gastric glands which open into gastric pits. There are three types of secretory cells in these glands: mucus secreting cells, oxyntic cells secreting hydrochloric acid and chief cells secreting pepsinogen (later converted to the pepsin). Smooth muscle mixes and moves food on by peristalsis. Small intestine
- ▼ The small intestine submucosa and mucosa form folds and villi which increase the surface area for the absorption of food and slow the movement of food.
- ▼ Each villus contains blood capillaries to absorb all nutrients, and a lymphatic capillary (the lacteal) to absorb fats. The cells of the villus bear surface projections called microvilli.
- ▼ Goblet cells secrete mucus whilst Paneth cells found in the crypts of Lieberkuhn between the villi secrete antibacterial lysosome.
- ▼ Brunners glands are restricted to the duodenum and secrete mucus and an alkaline fluid to neutralise the acid chyme.
- ▼ The large intestine consists of the colon where most water is absorbed, the caecum and appendix which are much reduced (vestigial) in humans, and the rectum into which faeces move before defaecation.
- ▼ The smooth muscle moves the food through the gut by waves of contractions (peristalsis).
- ▼ Carbohydrates are digested by carbohydrase enzymes e.g. amylase in the saliva in the mouth and in pancreatic juice digests starch to maltose; on the epithelium cells of the ileum maltase digests maltose to glucose; sucrase digests sucrose to glucose and fructose; and lactase digests lactose to glucose and galactose.

Student Activity

Materials

- Model of human skull for dentition.

□ OHT Human gut

Procedure

Make an annotated sketch of the human gut in relation to digestion and absorption.

Set Work

Make a table of the main differences in the structure of the wall in the oesophagus, stomach, duodenum and ileum.

Notes:

Unit 2H

Exchange, transport and reproduction in humans

2H.2 Transport of materials

Circulation

Topic Guide

Session: _____

Check List

- ▼ The functions of the circulatory system include the transport of oxygen and carbon dioxide between the lungs and the tissues of the body, metabolites to and from the gut, liver and kidneys, metabolic wastes from the liver to the kidneys, and hormones from and between the endocrine glands.
- ▼ In single circulations blood only passes through the heart once on each complete circulation of the body.
- ▼ Means that blood passes through two sets of capillaries on each circulation, respiratory surface and body tissues.
- ▼ Represents large resistance to overcome before blood returns to heart, resulting in slow flow and low pressure in veins which are typically large blood sinuses to lower resistance to flow.
- ▼ In closed systems blood almost entirely restricted to vessels: arteries, arterioles, capillaries, venules, veins.
- ▼ Tissue fluid exuded to bathe tissues directly.
- ▼ Double circulation blood passes through heart twice on each circulation.
- ▼ Pressure relatively low to lungs.
- ▼ Pressure raised for systemic circulation to body giving high pressure and fast flow.

Student Activity

Materials

- ☐ OHT Mammalian heart
- ☐ OHT Closed double circulation diagram

Procedure

- ☐ OHT Closed double circulation. Explain the advantages of a double circulation (it only occurs in birds and mammals - the 'warm blooded' vertebrates).

Now relate this diagram to the structure of the heart using the ☐ OHT.

Set work

Write 10 lines on 'Why the human heart can be considered as two separate pumps.'

Notes: _____

Unit 2H

Exchange, transport and reproduction in humans

2H.2 Transport of materials

The circulatory system

Topic Guide

Session:

Check List

- ▼ External appearance of heart shows small 'flap-like' atria, coronary blood vessels, fat deposits, and major vessels entering and leaving (venae cavae, pulmonary arch, and aortic arch).
- ▼ Coronary arteries arise just above the pocket valves at the base of the pulmonary and aortic arches, and supply the cardiac muscle of the heart wall with its own blood supply. Coronary veins return the blood to the right atrium.
- ▼ Internal structure of two atria and two ventricles.
- ▼ Chordae tendinae and muscles prevent back-opening of bicuspid and tricuspid valves when ventricles contract (ventricular systole).
- ▼ Pocket valves at base of pulmonary artery and main aorta prevent backflow of blood into ventricles when they relax (ventricular diastole).
- ▼ Atria walls thinner than ventricle walls.
- ▼ Left ventricle wall thicker than right ventricle wall to pump blood around body (systemic circulation).
- ▼ Right ventricle wall thinner than left ventricle wall as only has to pump blood via pulmonary circulation around lungs, where reduced pressure prevents formation of tissue fluid in alveoli.
- ▼ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.

Student Activity

Materials

- Sheep/Pig's heart with atria and major vessels intact for demonstration dissection
- Dissection materials
- OHT Diagram of heart structure

Procedure

It is usually difficult to obtain hearts with all the major vessels in place, and frequently they also have the tops of the atria sliced off.

The biggest problem is reconciling the actual structure of the heart with the diagrams which are used to simplify and clarify the structure.

If a heart with all the vessels attached is obtainable, connecting clear flexible tubes of the appropriate diameter to the vessels enables water to be pumped through the heart simply by squeezing it.

If a range of hearts are dissected note the variation of structure that occurs.

Filling aorta with water allows examination of the pocket valves from above.

It is difficult to choose the 'best' way of dissecting the heart, and possibly more may be seen if a range of methods of opening the heart are used.

Set work

Make a simple diagram of the heart chambers and annotate it with regard to the appearance of the real heart.

Notes:

Unit 2H

Exchange, transport and reproduction in humans

2H.2 Transport of materials

The circulatory system

Topic Guide

Session: _____

Check List

- ▼ The cardiac cycle refers to the events of a complete filling and emptying of the heart.
- ▼ It is a continuous cycle, the start point of which can be taken when heart is empty and all valves shut.
- ▼ Atria fill and internal pressure rises forcing bicuspid and tricuspid valves open.
- ▼ Ventricles fill so that whole heart full.
- ▼ Atria contract (atrial systole) so that ventricles overfilled and stretched.
- ▼ Ventricles contract with a force proportional to their degree of stretch (ventricular systole).
- ▼ Blood forced up shutting bicuspid and tricuspid valves (first heart sound) and opening pocket valves as blood forced up pulmonary artery and aorta.
- ▼ Ventricles relax (ventricular diastole) blood falls back in pulmonary artery and aorta shutting pocket valves (second heart sound).
- ▼ Rate modified by sinu-atrial node (pacemaker) in wall of right atrium.
- ▼ Cardiac muscle is myogenic.
- ▼ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ▼ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ▼ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from where it radiates up through the walls back to the connective tissue barrier.
- ▼ Detected by electrodes on the skin as an ECG.
- ▼ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline.
- ▼ Pressure receptors in the main veins and arteries close to the heart detect pressure changes and regulate the cardiac output by reflexes via the medulla of the brain.
- ▼ All influences on heart coordinate heart rate and therefore blood supply to body with demands of body.

Student Activity

Materials

- Blood pressure measuring device and stethoscope
- ECG charts
- Practical Work Sheet:

An investigation of the effects of physical activity on pulse rate

- OHT Diagram of heart and SA node
- OHT Graph/chart of the cardiac cycle

Procedure

Perform the Step test and integrate the following.

Listen to heart sounds using stethoscope. Relate sounds to valve closures and stages of cardiac cycle.

Observe the demonstration of the measurement of systolic and diastolic blood pressure.

Demonstrate venous blood pressure.

Stand back to a wall and raise arm to level with heart. At this point veins in hand and arm should

still be visible (if visible in the first place). Mark this position. Get an assistant to raise the arm until veins 'collapse' mark this new position. Note the distance (d) between the two marks in cms. Calculate the venous blood pressure from:

$$(d-10) \times 1.055/13.55 \times 10 = \text{answer in mm.Hg}$$

Observe copies of ECG charts (in groups) and explain how they are obtained.

Relate the ECGs to the events illustrated on the OHT.

Set work

Record your pulse rate before rising each morning and just before going to bed each evening for a week, and plot as a graph of pulse rate against time.

Artificial pacemakers re-establish a fixed rhythm in those suffering erratic heart beats. Explain the effect on daily activities of having an artificial pacemaker fitted.

Unit 2H

Exchange, transport and reproduction in humans

2H.2 Transport of materials

The circulatory system

Topic Guide

Session: _____

Check List

- ▼ Elasticity of arteries is important in smoothing flow of cardiac output - the pulse.
- ▼ Finer branches and arterioles main site of generation of resistance to blood flow and generation of blood pressure.
- ▼ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ▼ Capillaries have large total cross sectional surface areas. Therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ▼ Diameter of capillary same as red blood corpuscles thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ▼ Plasma minus proteins exuded through thin walls to bathe tissues directly.
- ▼ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ▼ Pocket valves ensure one way flow back to heart.
- ▼ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

Student Activity

Materials

- Microscopes and slides of T.S artery and vein, and T.S. alveoli for T.S. capillaries.
- 2mm (ring) sections cut from the aorta and vena cava of a sheep/pig's heart in saline
- 40 cm length of fishing line.
- Assorted weights (10 to 100g) and hook for their suspension.
- Retort stand and 2 clamps.
- Ruler

Procedure

Make annotated sketches of T.S. artery, vein and capillaries.

Investigation into stretch and recoil of arteries and veins.

Set up a retort stand with the section of artery or vein suspended by the fishing line to a clamp. A second piece of fishing line is used to suspend different weights from the vessel. A ruler is positioned and clamped to enable any stretching of the vessel to be measured. The exercise consists of adding weights to the line. Measure the distance stretched as a 10g weight is added and record it as a percentage of the original vessel

length, then take off the weight and measure how far the vessel recoils. Record this also as a percentage of the original vessel length. Repeat, increasing the weight by 10g each time. How do the stretch and recoil properties of arteries a veins differ. Suggest a reason.

Setwork

Make a table to compare the structure and functions of arteries, veins and capillaries.

Notes: _____

Unit 2H

Exchange, transport and reproduction in humans

2H.2 Transport of materials

Blood and body fluids

Topic Guide

Session: _____

Check List

- ▼ Reversible combination of haemoglobin and oxygen in the capillaries of the pulmonary circulation is a physical association.
- ▼ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor.
- ▼ Gas exchange at tissues is in effect the reverse of that at the lungs similarly explained in terms of diffusion gradients (partial pressure gradients).
- ▼ Bohr effect applies to conditions in tissues illustrates how conditions of increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ▼ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen. Note that the placental artery is some distance from the lungs of the mother and therefore not particularly well oxygenated.
- ▼ Myoglobin is a pigment found in red (endurance type) muscle fibres and has a greater affinity for oxygen than does haemoglobin, so that it is capable of loading up high with oxygen from relatively lower saturated haemoglobin. It acts as an intermediary between oxygen in the blood and the muscle fibres.
- ▼ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.

Student Activity

Materials

- ☐ OHT Bohr effect
- ☐ Myoglobin, fetal and adult haemoglobin dissociation curves.

Procedure

Revise structure of haemoglobin. Remember that there are four possible attachment sites for oxygen on each molecule of Hb. When all the sites on all the molecules are occupied the blood is 100% saturated.

☐ OHT shows that this situation occurs in the lung alveoli. Where oxygen is being used by respiring tissues a concentration gradient develops with the result that oxygen dissociates from Hb and diffuses into the tissues. Annotate a copy of the OHT chart.

Bohr effect. Note the effect of increasing carbon dioxide on the dissociation of oxygen using the ☐ OHT. Annotate a copy of this OHT.

Fetal haemoglobin. Note the difference between adult and fetal Hb using the ☐ OHT. Annotate a copy of this OHT.

Remember that these curves are to be looked at as 'loading' with oxygen at the lungs from left to right; and 'unloading' oxygen at the tissues from right to left.

Set work

Write a paragraph on how increased muscle activity has the effect of increasing the release of oxygen from the oxyhaemoglobin in the erythrocytes.

Notes: _____

Unit 2H

Exchange, transport and reproduction in humans

2H.3 Human ecology

Adaptations to extreme environments

Extremes of temperature

Topic Guide

Session: _____

Check List

- ▼ Extremes of environmental temperature pose problems for the body's homeostatic mechanisms which strive to keep the core temperature at the optimum (normal) 37°C.
- ▼ Homeostasis is a dynamic equilibrium 'hunting' around the optimum
- ▼ In addition even under constant optimum external conditions when at rest, there are diurnal (daily) variations of body temperature as a result of diurnal rhythms of brain and hormonal activity.
- ▼ The skin has thermoreceptors and detects the heat gradient between it and the surroundings, and the hypothalamus of the brain measures the body temperature against the target of 37°C.
- ▼ Blood vessels in the skin are dilated or constricted according to the need to lose more or less heat over the skin by conduction, convection and radiation.
- ▼ Sweat glands secrete sweat onto the surface of the skin to lose heat by evaporation (latent heat of evaporation).
- ▼ Heat stress is caused the body attempting to regulate the core temperature in a hot climate without adequate supplies of water and electrolytes (salts).
- ▼ Sweating results in the loss of water leading to moderate or severe dehydration if not replaced, and the associated loss of salts can lead to heat cramps.
- ▼ Visitors to hot climates can acclimatise after a period as a result of an increase in efficiency of the heat regulating mechanisms.
- ▼ People native to the conditions are adapted genetically to low body fat, and large surface area to volume ratio.
- ▼ The body can withstand a greater drop of temperature than it can a rise, because with a drop in temperature metabolism slows so damaging processes are also slowed.
- ▼ Windchill and exposure lead to hypothermia and below a certain critical temperature the circulation to the extremities and the limbs is shut down in order to conserve the core temperature.
- ▼ The reduction in blood flow leads to cold injury, trench foot and frostbite.

Student Activity

Materials

- Microscopes and slides of sections of human skin.

Procedure

Make annotated sketches of the slides of human skin with respect to those features involved with temperature control.

Set work

Explain why one of the symptoms of hypothermia is a feeling of warmth.

Notes:

Unit 2H

Exchange, transport and reproduction in humans

2H.4 Human reproduction and development

Reproduction

Topic Guide

Session: _____

Check List

- ▼ The male reproductive system consists of the testes which produce spermatozoa by meiosis.
- ▼ Copulation transfers them to the female via a system of tubes and erectile tissue.
- ▼ Accessory glands are important in secreting substances essential for successful fertilisation.
- ▼ The female system consists of ovaries which release egg cells (ova) into the abdominal cavity, from where they are swept down the oviducts by ciliated epithelium, into the uterus.
- ▼ The uterus connects to the exterior by the vagina.
- ▼ Offspring result from the fusion of gametes, forming a zygote.
- ▼ This fusion of gametes involves various genetic mixing events and therefore leads to genetic variation in offspring.
- ▼ These genetic mixing events include events in the nuclear division (meiosis) involved in the production of gametes, and in the random fusion of gametic nuclei from different sexes.
- ▼ In the first phase of meiosis (Meiosis I) the two sets of chromosomes pair up, so that chromosomes occur in homologous pairs. Each chromosome is duplicated into two chromatids, so one pair of chromosomes is made up of four chromatids.
- ▼ Meiosis is a reduction division in which the diploid number of chromosomes (two sets) is reduced to the haploid (one set).
- ▼ The homologous chromosomes of a pair entwine, one chromatid of each pair breaks and rejoins with the broken chromatid of the other pair, in a process known as genetic recombination or crossing over.
- ▼ Cross overs are visible under the light microscope and are known as chiasmata (Greek for crosses), they result in the exchange of genes (alleles) between homologous chromosomes.
- ▼ The chiasmata align on the equator of the nuclear spindle apparatus (NSA), before the homologous chromosomes repel each other to opposite poles.
- ▼ Either chromosome of each pair can go to a particular pole, resulting in mixing of the original sets (independent assortment).
- ▼ Two daughter nuclei are thus formed, each with one (haploid) set of chromosomes, with each chromosome composed of two chromatids.
- ▼ The second phase of meiosis (Meiosis II) involves the centromeres of the chromosomes aligning on the equator of a each of two new NSA formed at right angles to the first.
- ▼ The chromatids then repel each other to form four new haploid nuclei.

Student Activity

Materials

- Microscopes and slides of meiosis
- OHT Male and female reproductive systems

Procedure

Examine the slides and make sketches of chiasmata

Set Work

Make simple line diagrams to show the behaviour of chromosomes during meiosis.

Notes: _____

Unit 2H

Exchange, transport and reproduction in humans

2H.4 Human reproduction and development

Development

Topic Guide

Session: _____

Check List

- ▼ Although the most rapid periods of human growth occur prior to birth, human growth curves, usually begin at birth (0 years).
- ▼ Growth curves are steeper in the first year and around puberty than at other times; infancy (birth to 3 years); childhood (3 -12 years) and adolescence (12-18 years).
- ▼ The effects of ageing (senescence) are becoming common sights and common medical problems. All systems of the body deteriorate gradually with age including the brain and nervous system, the skeletal system, the respiratory system, the circulatory system, and the reproductive system.
- ▼ Osteoarthritis is a very common degenerative condition which causes pain and stiffness and loss of movement in the large weight bearing joints of the body such as the hips and knees and back, as a result of the gradual loss of cartilage from the surfaces of the joints (articular cartilage).
- ▼ Osteoporosis, a condition involving a loss of bone mass and increased risk of bone fracture, is a feature of ageing which affects all older people to some extent, but is particularly severe in elderly women.
- ▼ Age above 40 years is a risk factor for all cardiovascular conditions (conditions relating to the functioning of the heart and blood vessels). This includes atherosclerosis, a condition in which the arteries become hardened and slightly narrowed by the deposition of fatty deposits
- ▼ This condition can lead to angina and coronary heart disease (CHD) and can increase the risk of stroke (through thrombosis or blood clots), two of the most important causes of death in Britain today.
- ▼ Prior to the menopause the risk of atherosclerosis and CHD is much greater in men than women, yet in post menopausal women rates are the same. The effect seems to be related to oestrogen levels.
- ▼ Men remain biologically capable of fathering children throughout their lifetime. In contrast, women are only fertile for around 30-35 years of their life after which they enter the menopause, a period of months or years during which the activity of the reproductive system declines.
- ▼ The menopause can bring about hot flushes (linked to high FSH and LH levels) and a range of psychological symptoms including anxiety and forgetfulness. Other common problems include reduced elasticity and increased risk of both osteoporosis and coronary heart disease.

Student Activity

Materials

- ☐ OHT Growth curves

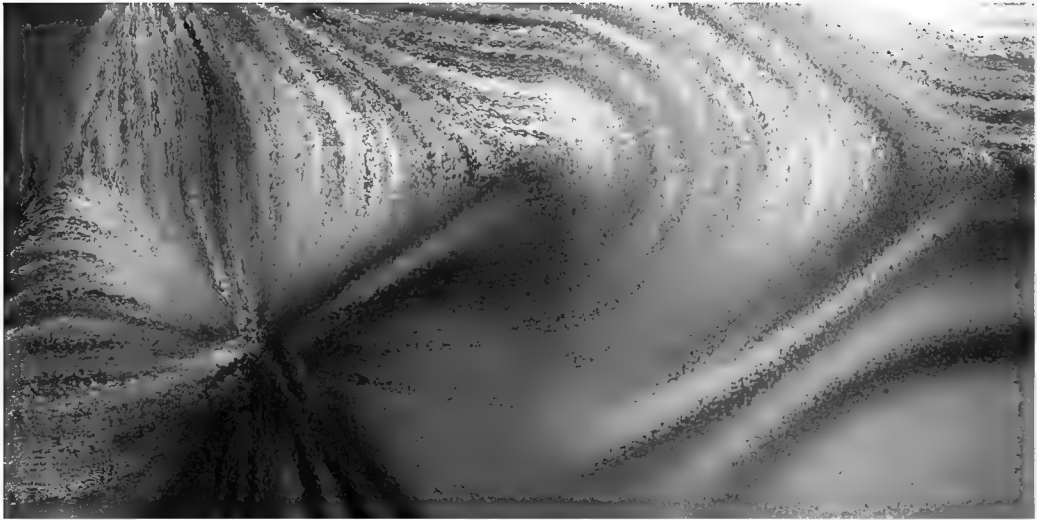
Procedure

Identify the main changes in gradient of the growth curves.

Set Work

List the common degenerative diseases associated with age.

Notes:



Session:

▼ Typically there is a maximum of four trophic levels in a food chain as a result of the losses of material and energy at each level.

Notes

Construct a food chain from the list compiled of producers and consumers in the ecosystem.

Session:

▼ Net primary production refers to that which is in excess of the plants own respiratory requirements and is potentially available to the next trophic level.

Notes:

Unit 3

Energy and the environment

3.4 Recycling of nutrients

Topic Guide

Session: _____

Check List

- ▼ The geological water cycle involves the evaporation of water into the atmosphere and its precipitation from the atmosphere (rain, snow, hail etc).
- ▼ Water is essential for life and living organisms exploit various water supplies. Transpiring plants play a major part in drawing water from the soil and evaporating it to the air.
- ▼ Much water drains away to deep lying deposits of porous rocks (aquifers) where it is essentially removed from the water cycle.
- ▼ The carbon cycle involves the cycling of carbon from carbon dioxide in the atmosphere (or hydrogen carbonate ions in aquatic ecosystems) to carbon containing organic compounds and back again.
- ▼ Photosynthesis converts carbon dioxide into organic materials which are exploited by consumers (and decomposers) and move through food chains and webs.
- ▼ Respiration of living organisms (including that of decomposers) releases carbon dioxide back to the atmosphere.
- ▼ Long living organisms e.g. trees act as temporary carbon sinks which remove carbon from the cycle for a period of time. More permanent sinks are represented by fossil fuels (coal and oil), and carbonates of shelled organisms which form chalk and limestone deposits.
- ▼ Microorganisms acting as decomposers play a major role in releasing carbon back into the cycle as carbon dioxide.
- ▼ Man now has a considerable effect on the carbon cycle by the combustion of fossil fuels (coal and oil) which releases carbon dioxide from these sinks in a very short time.
- ▼ The principle conversions in the nitrogen cycle are between the three reservoirs of nitrogen and its compounds: the atmosphere, soil and water, and living organisms.
- ▼ Nitrogen fixing microorganisms, e.g. *Rhizobium* bacteria can convert nitrogen to nitrogen containing organic compounds such as amino acids which are the building blocks of proteins.
- ▼ *Rhizobium* forms a mutualistic association in the root nodules of certain plants (Papilionaceae).
- ▼ Dead organic matter decomposes and releases nitrogen containing compounds, e.g. ammonia. and ammonium compounds.
- ▼ Chemosynthetic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* use these as a source of energy for their synthetic processes, which result in the production of nitrate ions.
- ▼ Plants take up ammonium and nitrate ions and combine them into amino acids and proteins, and other nitrogen containing compounds, e.g. ATP and DNA.
- ▼ Animals consume plants and each other and these nitrogen containing compounds form an essential part of the diets of consumers.
- ▼ Animals die and decompose and the cycle continues.
- ▼ Anaerobic denitrifying bacteria convert nitrates back to nitrogen.
- ▼ Man now has a considerable effect on the Nitrogen cycle by the use of artificially produced nitrate fertilisers.

Student Activity

Materials

- ☐ OHT Nitrogen cycle

Procedure

Contrast the flow of energy through an ecosystem with the recycling of bioelements.

Set work

Suggest a reason why insectivorous plants are found on nitrogen poor soils.

Notes:

Unit 3

Energy and the environment

3.5 Energy resources

3.6 Human influences on the environment

Topic Guide

Session: _____

Check List

- ▼ The use of fossil fuels (oil and coal) is unsustainable as they are finite resources. They represent the accumulation of millions of years of photosynthetic activity, and their combustion over the last century or so has returned all the carbon from these 'sinks' to the atmosphere.
- ▼ The carbon cycle has become distorted and the carbon dioxide levels in the atmosphere are rising.
- ▼ Energy resources can and need to be used in a sustainable manner.
- ▼ To do so use must be made of solar energy, wind, wave, hydroelectric schemes, and organic matter the combustion of which represents a carbon balance.
- ▼ Fast growing biomass (eucalyptus trees), gasohol (alcohol) from cane sugar, and biogas from the fermentation of domestic and agricultural wastes, release carbon dioxide by their combustion in proportion to that which was absorbed by photosynthesis in their production.
- ▼ Increasing population pressure and economic demands lead to deforestation. Removal of tree cover on poor soils can lead to the collapse of the entire ecosystem and the formation of deserts (desertification).
- ▼ Under less extreme conditions deforestation can lead to isolation of small patches of woodland which are insufficient to support the original forest communities with their rich biodiversity.
- ▼ If the cleared areas are used for crop production there is a dramatic drop in the biodiversity and hence stability of communities, and massive monocultures are prone to pest attack.
- ▼ Atmospheric pollution as a result of the combustion of fossil fuels results in acid rain (sulphuric and nitric acids), and greenhouse gases (e.g. carbon dioxide) which absorb solar radiation and lead to a warming of the atmosphere.
- ▼ Water pollution results from the release of the many toxic waste products of man into the water system.
- ▼ Acid rain acidifies water and destroys aquatic ecosystems.
- ▼ Raw human and animal sewage has a high organic content and its oxidation by aerobic microorganisms depletes water of its oxygen.
- ▼ Run-off of excess nitrates and phosphates from artificial fertilizers in the soil cause eutrophication of the water which can trigger excess algal growth (algal blooms), which can deplete other essential nutrients, leading to death of the algae, their aerobic decomposition, and depletion of oxygen in the water.
- ▼ Depletion of oxygen in aquatic ecosystems leads to the death of aerobic organisms and the collapse of the ecosystem into anaerobic conditions, which cannot be simply reversed by oxygenation.
- ▼ European legislation exists to control air and water quality.

Student Activity

Materials

- ☐ OHT Depletion of oxygen in water

Procedure

Debate the complex issues involved but with a firm scientific basis.

Set Work

Summarise the debate on man's impact on the environment.

Notes: _____

Biology or Biology (Human)



Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

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Contents

Unit 1

1.1	Qualitative and quantitative tests for substances of biological importance	3
1.2	The effect of temperature on the activity of the enzyme catalase	7
	The action of Immobilised Lactase enzyme on Lactose in milk	11
	The effect of pectinase enzyme on the extraction of juice from apples	14
1.3	The setting up and use of a light microscope to view slides of suitable tissues and cells, and the making of accurate drawings of cells and plans of tissues	16
	Use of a suitable graticule to make measurements and understand the concept of scale in relation to drawings done from specimens seen using the light microscope	19
1.4	Preparation of an onion root tip squash to demonstrate stages in mitosis using a light microscope	23

Unit 2 (Biology only)

2B.1	The rate of respiration of small organisms or living tissues using a simple respirometer	26
2B2	Demonstrations and measurements of transpiration using a potometer	31
	Stomatal counts	34
	The microscopic examination of stained blood films and the identification of cells	36
2B.4	The factors affecting the growth of pollen grains	38
	Observation of slides of slides of insect testis squash	40
	Microscopic examination of the histology of ovary and testis	42

Unit 2H (Human Biology only)

2H.1	The estimation of vital capacity using simple apparatus	44
	Quantitative comparisons of inspired and expired air	50
2H.2	An investigation of the effects of physical activity on pulse rate	56
	The microscopic examination of stained blood films and the identification of cells	61
	Microscopic examination of the histology of ovary and testis	63

Unit 3

3.3	The estimation of pyramids of number and of fresh biomass using simple techniques for the collection and determination of fresh biomass	65
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Practical Work Guide

An Introduction

This guide is designed to provide material for supervisors to use at their discretion for the practical work based on the AS specifications for Units 1, 2B, 2H and 3. Only practical exercises specifically mentioned in the specifications are included.

All of the exercises provide opportunities to contribute to fulfilling the Aim to:

promote an appreciation of the importance of experimental and investigatory work in the study of biology and develop an understanding of the link between theory and experiment and of scientific methods.

Equally all of the exercises provide opportunities to contribute to fulfilling Assessment Objective AO3 Experiment and investigation:

Candidates should be able to:

devise and plan experimental and investigative activities, selecting appropriate techniques;

demonstrate safe and skillful practical techniques;

make observation and measurements with appropriate precision and record these methodically;

interpret, explain, evaluate and communicate the results of their experimental and investigative activities clearly and logically using biological knowledge and understanding and using appropriate specialist vocabulary.

The Guide is **not** designed to address the specific requirements for AS Unit 3: Paper 01 T1 An Individual Investigation.

The responsibility for safe and correct practice rests entirely with the designated supervisor, to whom the methods are offered as a source of information only.

Hazard Cards as produced by, for example CLEAPS, should be displayed wherever necessary.

CLEAPS, School Science Service, Brunel University, Uxbridge, UB8 3PH

Unit 1:

Molecules and Cells

1.1 Molecules

Practical work to include qualitative and quantitative tests for starch, reducing and non-reducing sugars and proteins using iodine solution, Benedict's reagent and biuret reagent, as appropriate.

Qualitative and quantitative tests for substances of biological importance

Introduction

These are a standard series of procedures to test for a variety of biological molecules. Traditionally they are referred to as 'food tests', but the specifications refer to them in the broader sense of testing for substances of biological importance.

A - Qualitative tests for starch, reducing and non-reducing sugars and proteins

Method - Test for starch - Iodine in potassium iodide solution test

- ▼ Place a small sample of starch solution on a spotting tile or in a test-tube.
- ▼ Add a few drops of iodine in potassium iodide solution.

The starch will combine with the iodine to give a deep blue-black colour. This test is very sensitive, so only tiny quantities are needed. The colour will fade after a while.

Method - Test for reducing sugars - Benedict's test

- ▼ Put on a pair of safety glasses. Collect a 500 cm³ beaker and fill it about half full with tap water. Place it on a tripod and gauze over a Bunsen burner and bring the water to the boil.
- ▼ Place a small quantity of reducing sugar solution (about 1-2 cm³) in a boiling tube. Add 2 cm³ of Benedict's reagent.
- ▼ Place the boiling tube in the waterbath and boil the tube and its contents for 3-4 minutes. Remove the tube from the waterbath using test-tube tongs and place it in a test-tube rack.

If the sample contains reducing sugars, a precipitate will be produced, and the colour will change from blue through green and yellow to brick-red, depending on the amount of sugar present. This test can thus be used to give an estimation of the amount of sugar present, provided the quantities of sugar solution and Benedict's reagent used are the same each time. A small amount of sugar will turn the solution green, larger amounts yellow and considerable quantities will turn it brick-red.

Method - Test for non-reducing sugars - Benedict's test

This test should be done if the previous test for reducing sugars gives a negative result.

- ▼ Place a fresh sample of sugar solution in a boiling tube (1-2 cm³) and add 1 cm³ dilute hydrochloric acid. Place the boiling tube in the boiling waterbath and boil it for 1-2 minutes.
- ▼ Remove the test-tube from the waterbath using tongs and place it in a test-tube rack. Allow to cool for a couple of minutes. Using a spatula, add small quantities of sodium hydrogen carbonate powder, until the mixture stops fizzing. (This will probably take about 3 small spatulas full: the sodium hydrogen carbonate neutralises the acid)
- ▼ Add 2 cm³ Benedict's reagent to the boiling tube and put it back in the waterbath, using the tongs. Boil it again for 3-4 minutes.

If non-reducing sugars (e.g. sucrose) were present in the original sample, the acid will hydrolyse them to monosaccharides, which are all reducing sugars: they will then give a green/yellow/brick-red precipitate with Benedict's reagent.

Method - Samples containing both reducing and non-reducing sugars

If you suspect that a sample contains both reducing and non-reducing sugars:

- ▼ Test with Benedict's reagent and obtain the precipitate as described above (using double quantities of sample and reagent)
- ▼ Filter the tested sample through filter paper, and collect the filtrate.
- ▼ Test the filtrate with Benedict's reagent.
- ▼ Continue this process, using the filtrate each time, until you no longer get a positive result with the Benedict's test.
- ▼ Add 1 cm³ dilute hydrochloric acid to the remaining filtrate and boil it to hydrolyse any non-reducing sugars it contains. Neutralise the mixture and re-test with Benedict's reagent.
- ▼ If a non-reducing sugar was present in the original sample there will be a positive result once more.

Method - Test for proteins - Biuret test

Place 2 cm³ of protein solution in a test-tube. Add 2 cm³ of dilute potassium hydroxide solution, then add 0.5 cm³ of dilute copper sulphate solution, a drop at a time. Shake the test-tube gently, then leave it in the test-tube rack for a few minutes.

If protein is present, a purple colour will develop after a few seconds (s). If there is no protein, the solutions will remain very pale blue from the copper sulphate solution.

II Quantitative biochemical tests for starch, reducing and non-reducing sugars and proteins

Introduction

All the quantitative tests described here are based on the fact that the positive results give a colour. The intensity of this colour is proportional to the quantity of substance present, and can be measured either by reference to a series of colour standards of known solutions, or preferably by means of a colorimeter. Alternatively Clinistix or their equivalent can be used.

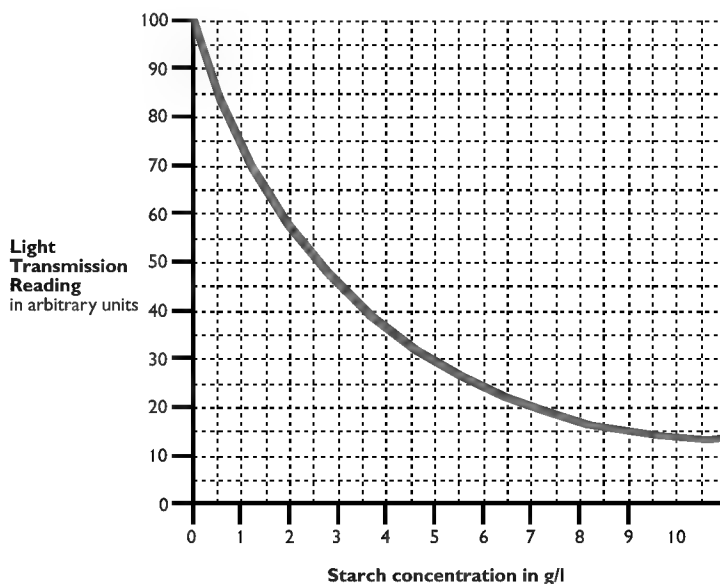
Method

The iodine test for starch, and the Benedict's test for reducing and non-reducing sugars can be made quantitative by controlling the quantities of solutions and samples more carefully, and using more precise methods of measuring the test result.

The result for the Benedict's test can be quantified by performing the test on a series of known concentrations of glucose solution, to produce a colour series, against which the results of tests on unknown concentrations can be compared. (The precipitate produced by the Benedict's test does not lend itself to the use of the Colorimeter which measures the absorbance of light).

The concentration of starch in a solution can be determined by reacting starch with iodine solution and measuring the depth of the blue / black colour produced, with a colorimeter. This can be quantified by reference to a calibration curve plotted from colorimeter readings of a series of known concentrations of starch solution.

Example of a calibration curve of colorimeter reading against starch concentration in g.dm^3



Teaching Notes

Motivation might be stimulated by suggesting that students are testing foodstuffs for a supermarket firm who have been told that some of their foods have been spiked: try adding starch to the milk, or injecting some fats into oranges, for example.

Alternatively, there is a good variation published in Journal of Biological Education, (Roger Law, 1995, "An A-level food test investigation", JBE, Volume 29, p251-252), which uses other tests as well, to analyse mock "stomach contents" from two animals. The idea is to decide whether they are carnivorous or herbivorous. This test uses some solutions which are a bit more risky than the usual ones (Schultz' reagent for cellulose, for example.) However, it can make an enjoyable change.

No member of the team has performed a quantitative test for proteins, other than those based on the 'clearing' of albumen by the activity of protease.

Requirements per student

Boiling tubes
500 cm³ beaker
Bunsen burner, tripod and gauze
Spotting tile
Filter funnel and filter paper
Small measuring cylinders or dropping pipettes

Test tubes
Test-tube rack
Test-tube tongs
Small spatula
Safety glasses

Benedict's reagent
Dilute hydrochloric acid
Sodium hydrogen carbonate powder
Iodine in potassium iodide solution
70-80% alcohol solution
Biuret 1% copper sulphate solution
Biuret 15% potassium hydroxide solution

Standard solutions of:
sucrose (5%), glucose (5%), Starch (1%), and albumin (5%).

Safety Considerations

The following chemicals need to be handled carefully:

Dilute hydrochloric acid – corrosive
Iodine in potassium iodide solution – irritant
80% alcohol – highly flammable
Biuret potassium hydroxide – corrosive

Safety glasses should be worn for the Benedict's test at least, you may prefer the students to wear them all the time.

The Benedict's reaction should be boiled in a waterbath – never allow students to heat the tube directly in the Bunsen flame.

Normal precautions for handling hot apparatus should be observed.

Unit 1:

Molecules and Cells

1.2 Enzymes

Practical work should include experiments to investigate the effects of temperature on enzyme activity using suitable enzymes.

Experiment to investigate the effect of temperature on the activity of the enzyme catalase

Introduction

Catalase catalyses the breakdown of hydrogen peroxide to oxygen and water.



The rate of production of oxygen can be measured, and gives a measure of the rate of the reaction.

Catalase is produced in cells to prevent the accumulation of hydrogen peroxide, which is toxic.

In this experiment potato tissue is used as a source of catalase.

The effect of temperature on the rate of this reaction will also be investigated.

TAKE CARE with the HYDROGEN PEROXIDE - wear safety glasses and try not to get any on your skin, wash off immediately if you do.

Method

▼ There are various pieces of apparatus that you can use to collect and then measure the volume of oxygen gas that will be evolved when the catalase in the potato tissue reacts with the hydrogen peroxide.

a The O₂ gas can be collected over water in an inverted measuring cylinder.

b The O₂ can be collected over water in the inverted barrel of a 20 cm³ syringe.

c The O₂ can be collected and measured in a manometer tube filled with coloured fluid, linked to the reaction vessel. You will be advised which method(s) to use.

The details below relate mainly to the 'inverted measuring cylinder' method.

▼ Using a cork borer a little smaller in diameter than your boiling tubes, cut some long potato cylinders. Using a knife (scalpel) carefully cut the potato cylinder into discs about 1mm thick.

▼ Place the discs into a few cm³ of pH7 buffer in a watch glass to keep them moist. You will need 50-60 discs.

▼ Using a boiling tube as the reaction vessel, place about 10 potato discs into the tube and just cover them with a measured volume of pH7 buffer.

continued

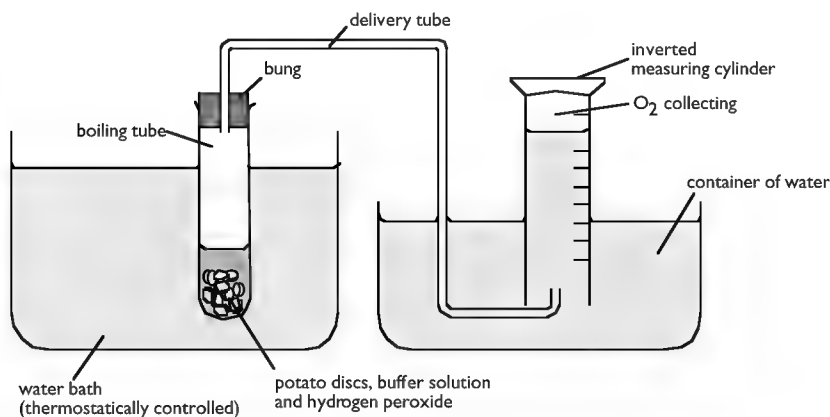
- ▼ Place the tube in a water bath, at the first temperature you intend to use, e.g. 20°C and allow the discs time to reach the correct temperature. Place a boiling tube of hydrogen peroxide into the water bath at the same time, so it also reaches the same temperature.
- ▼ Assemble your apparatus; using a rubber bung with a delivery tube inserted, and check that this will fit under the inverted 25 cm³ measuring cylinder full of water in its container of water. You may have to use a clamp stand to support the cylinder.
- ▼ When you are ready, measure 5 cm³ of hydrogen peroxide (H₂O₂) in a syringe. Carefully loosen the bung of the boiling tube, and very quickly and safely add the peroxide. Replace the bung and start your stopclock, tap or shake the tube if necessary to mix the contents.
- ▼ Record the volume of oxygen produced every 30 s for 3 minutes.
- ▼ Remove the boiling tube, wash it out and add 10 new discs and the same volume of pH7 buffer as used before. Put the tube back in the water bath and carefully raise the temperature by 10°C.
- ▼ Refill the measuring cylinder with water (if necessary).
- ▼ Add 5 cm³ hydrogen peroxide to the boiling tube, quickly replace the bung, start the stopclock and take your readings as before.
- ▼ Repeat your experiment at 30, 40, 50 and 60°C using a new set of potato discs each time.

Look at the rate at which the oxygen has been produced during each 30 second period. Can you explain your results in terms of an enzyme reacting with its substrate?

Calculate the mean amount of O₂ produced during the 3 minute period, at each temperature. Plot a graph of these figures against temperature.

Explain how you could improve your method to obtain more reliable results.

Plan how you could adapt this experiment to investigate the effect of pH, substrate concentration, or enzyme concentration, on the action of Catalase. Check your new plan with your supervisor, then carry out your investigation and write a full report including analysis of results, conclusion and evaluation etc.



Teaching Notes

This practical usually works quite well and it is a good exercise for students to demonstrate their manipulative skills. A number of methods can be used in this experiment to measure the volume of oxygen produced, as mentioned on the student sheet: e.g. over water in an inverted measuring cylinder, over water in the barrel of a syringe (a small piece of rubber tubing is attached to the narrow end of the syringe which has a screw clip so the barrel can be filled with water) or in any simple manometer.

A bit of juggling with the number of potato discs and the volume of peroxide (or its concentration) may be necessary to achieve a good result. But students using the inverted measuring cylinder method at 40°C recently obtained results of:

O₂ produced: 30s/5 cm³, 60s/2 cm³, 90s/1.5 cm³, 120s/1.0 cm³, 150s/0.5 cm³, 180s/0.5 cm³.

Hydrogen peroxide can be added from a syringe, the needle of which is inserted through the cork, to improve accuracy.

If the students are going on to measure the effects of pH, they will need to be supplied with quantities of buffers: pHs suggested are 4, 5, 6, 7, 8, 9. They will need only a few cm³ of each buffer per student.

Substrate concentration can be varied using different concentrations of hydrogen peroxide, such as 5 vol., 10 vol., 15 vol., and 20 vol.

Effect of enzyme concentration can be measured by varying the number of potato discs used. Alternatively you could vary the size of the discs (either diameter or thickness). It is quite important that the discs are cut to the same sizes for this version of the experiment. This would also allow them to consider the effect of surface area to volume ratio.

continued

Requirements per student (measuring cylinder method)

Boiling tube
Large beaker (500 cm³)
Bunsen burner, 2 tripods and gauzes or
thermostatically controlled water bath 1 tripod & gauze
Bung with delivery tube
Measuring cylinders 25 cm³ and 10 cm³
Trough or equivalent
Cork borer 10 mm diameter (No6)
Watch glass
2 100 cm³ beakers
5 cm³ syringe or dropping pipette
1 clamp stand
Stopclock
Thermometer
Knife/scalpel
50 cm³ pH 7 buffer
50 cm³ 20 volume Hydrogen peroxide
Potato

Safety Considerations

Use of the sharp knife and cork borer need care.

Hydrogen peroxide is an oxidant, and needs to be kept away from heat and stored in a fireproof cabinet.

H₂O₂ can also be irritant or corrosive at strong concentrations, so care is needed especially with the 15/20 volume.

Safety glasses, overalls, and disposable gloves should be worn, and skin contact avoided.

Unit 1:

Molecules and Cells

1.2 Enzymes

Practical work should include experiments to illustrate enzyme immobilisation using lactase.

Experiment to investigate the action of Immobilised Lactase enzyme on Lactose in milk

Introduction

Immobilised enzymes and cells are used increasingly in biotechnology, as they allow easier processing and harvesting of products. The enzyme or whole cell preparation is mixed with a solution of a gel based on alginate or a similar polymer, usually extracted from seaweed. Once they are mixed, the gel is treated to make it set. The beads or mesh can then be used in a column or similar flow system.

Using enzymes in this way has a number of advantages:

The beads are simple and rapid to produce; the process can be carried out under sterile conditions if necessary, so production can be kept clean

The process is gentle on the enzymes, causing little damage

It stabilises the enzymes, making them more resistant to heat, pH changes etc.

The enzymes can be used and re-used for long periods

Harvesting is simple, as the beads can be removed from the substrate and products easily, for example by sieving

If the beads or mesh are placed in a column system, a continuous flow process can be set up, which makes production more economic.

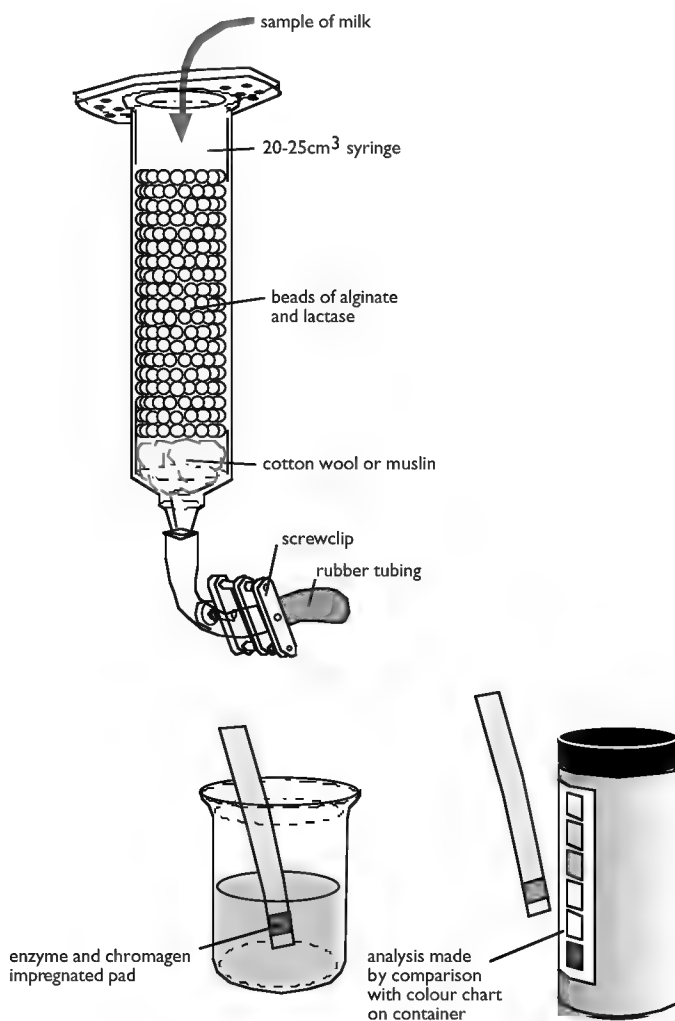
Method

- ▼ Collect 20 cm³ of 2% sodium alginate solution.
- ▼ Stir it with a glass rod to ensure an even consistency.
- ▼ Dissolve 1.4g calcium chloride in 100 cm³ distilled water.
- ▼ Add 2 cm³ of lactase solution to the alginate gel, and stir to mix.
- ▼ Draw some of the alginate mixture into a syringe. Expel it drop by drop into the calcium chloride solution, from a height of about 10 cm: this will allow it to form beads.
- ▼ Leave the beads to stand in the calcium chloride solution for 10 minutes, to allow the beads to set completely.
- ▼ Drain the beads through a sieve or tea strainer and rinse with tap water.
- ▼ Place a small piece of cotton wool or muslin cloth in the bottom of a 20 cm³ syringe (or larger) to prevent the beads blocking the nozzle. Place a short piece of rubber tubing over the nozzle of the syringe and put an efficient screwclip over the tubing. This will allow you to control the flow of milk through the column.
- ▼ Support the syringe in a clamp stand, nozzle downwards, and fill it with the alginate beads containing lactase, to within 1 cm of the top. (See diagram)

continued

- ▼ Collect a 50 cm³ sample of fresh milk, and transfer 5 cm³ into a test tube. Label it "No run" and put the test tube in a rack. Pour the rest of the sample slowly through the column, collecting the treated milk in a clean 50 cm³ beaker at the bottom.
- ▼ Take a 5 cm³ sample of the treated milk, put it in a test tube and label it 'Run 1'. Slowly pour the rest of the milk through the column again, and collect in a beaker.
- ▼ Take a new 5 cm³ sample, label it 'Run 2', and repeat the process once more. Collect a final sample of treated milk and label it 'Run 3'.
- ▼ Test each of the four milk samples you have taken with a Clinistix strip, to measure the quantity of glucose in each of the samples.

How would this process assist people who suffer from lactose intolerance?



Teaching Notes

The alginate solution and the calcium chloride solution can be prepared in advance, so the students can start making the beads immediately. Also, 3-4 sieves will usually be enough for a whole class.

The lactose solution is quite expensive, but it needs to be used neat, as supplied, or the enzyme reaction is very slow. It can be obtained from biological suppliers, or from the National Centre for Biotechnology Education, University of Reading, Whiteknights, Reading RG6 2AJ.

This practical works well, and the students usually enjoy making up the beads. A similar process can be used to prepare other immobilised enzymes e.g. sucrase (invertase), or whole cell samples e.g. yeast.

This experiment would make a good basis for a student project, for example trying different quantities of enzyme, or different sizes of beads to get the optimum efficiency in a simple column. They could also try different temperatures or using different pH-buffered solutions, to explore the improved stability of immobilised enzymes over non-immobilised ones.

Requirements per student

- 3 x 50 cm³ beakers
- 2 x 100 cm³ beakers
- 1 x 250 cm³ beaker
- 4 test tubes
- Test tube rack
- Glass stirring rod
- Sieve or tea strainer
- 5 or 10 cm³ syringe
- Clamp stand
- 20 or 25 cm³ syringe with rubber tubing & screw clip
- Distilled water
- 20 cm³ of sodium alginate solution
- 1.4 g calcium chloride
- 2 cm³ Lactase solution (as supplied).
- 50 cm³ sample of fresh milk
- 4 Clinistix (or similar) test sticks for glucose

Safety Considerations

Unless the practical is carried out in a food preparation area, with equipment used exclusively for food preparation, it is best not to allow the students to taste the milk preparations.

(After: Practical Biotechnology - National Centre for Biotechnology Education)

Unit 1:

Molecules and Cells

1.2 Enzymes

Practical work should include experiments to illustrate the use of pectinase in the production of fruit juice.

Experiment to investigate the effect of pectinase enzyme on the extraction of juice from apples

Introduction

Pectinase is used extensively during the production of commercial fruit juices, especially apple juice, which can be quite difficult to extract from some varieties of apple. The apples are pulped and heated to 30°C before the enzyme is added. After up to 2 hours of pectinase treatment (the time depends on the type of apple and the dosage of enzyme), the pulp is squeezed. The yield of juice can be increased by as much as 20%.

Commercial pectinases are obtained from fungi.

Pectinase breaks down the pectin of the middle lamella which occurs between the walls of the fruit cells. Otherwise the pectin forms a gel which slows the release of the cell contents.

Method

- ▼ Collect two medium-sized apples of different varieties and chop them (peel, core and all) into fine pieces.
- ▼ Weigh the material produced by each apple and then divide each sample into two equal portions.
- ▼ Place the four samples into beakers and label them carefully; e.g. Variety 1 with A and B; and variety 2 with C and D.
- ▼ Add 2 cm³ of pectinase solution to samples A and C, and 2 cm³ distilled water to B and D. Mix the contents of each beaker with a clean glass rod.
- ▼ Place the beakers into a water bath set at 35-40°C and incubate for about 20 minutes.
- ▼ Prepare four filter funnels lined with coffee filter paper and filter the contents of each beaker into measuring cylinders. Leave until all the juice has dripped through.
- ▼ Note the volume of apple juice which has collected in each of the four cylinders after 5, 10, 15 minute intervals.
- ▼ In your conclusion compare and explain the results from beakers A/B, and C/D; and then A/C & B/D.
- ▼ Suggest improvements to the method that you have used.

NB: Do not attempt to drink the juice you have produced: This practical uses a much stronger solution of pectinase than is used in commercial extraction!

Teaching Notes

The pectinase enzyme can be obtained from NCBE, Dept. of Microbiology, University of Reading, Whiteknights, Reading, RG6 2AJ. It should be diluted 50:50 with water before immediately before use.

The practical can also be used as the basis for project work, by investigating the conditions used for extraction, e.g. volume of enzyme or incubation temperature. An additional twist is to incubate the juice for 15-20 minutes before adding the enzyme: this is done in industry to allow enzyme inhibitors in the pulp to oxidise and should enhance the extraction rate. The extraction can be compared with and without the waiting time.

Requirements per student

- A chopping board
- A sharp knife
- 4 x 100 cm³ beakers
- 2 x 10 cm³ measuring cylinders
- 4 x 50 cm³ measuring cylinders
- 4 filter funnels, with filter papers
- 4 glass stirring rods
- Water bath set at 35-40°C
- Balance
- Stopclock
- 4 cm³ pectinase solution (diluted)
- 4 cm³ distilled water
- 2 medium-sized apples (different varieties)

Safety Considerations

Care should be taken while handling the knife to cut up the fruit.

The students should not be allowed to drink the juice produced, as the concentration of enzyme used is much stronger than that used commercially.

(After: Practical Biotechnology - National Centre for Biotechnology Education)

Unit 1:

Molecules and Cells

1.3 Cellular Organisation

Practical work should include the setting up and use of a light microscope to view slides of suitable tissues and cells. Candidates should be able to make accurate drawings of cells and plans of tissues and understand the concept of scale in relation to their drawings.

The setting up and use of a light microscope to view slides of suitable tissues and cells, and the making of accurate drawings of cells and plans of tissues

Introduction

Plant and animal cells are going to be examined and drawn under the light microscope. It is better to draw the low power plans first, in order to establish the overall structure, before drawing high power details of a few cells of a selected tissue.

Method

- ▼ Examine the prepared slide of a leaf section under the low power ($\times 4$) objective lens.
- ▼ Identify the tissues visible, and draw a plan diagram of the specimen, you are only showing the layers, so you do not need to draw individual cells. Label the tissues visible in your specimen, and annotate your labels with extra information.
- ▼ Calculate the magnification of the drawing:

Magnification by microscope = Eyepiece lens magnification $\times$ objective lens magnification

Note this figure near to the title of your drawing. Now correct the magnification for the size of your drawing, that is the number of times your drawing is larger than the image seen down the microscope, e.g. twice the size ($\times 2$).

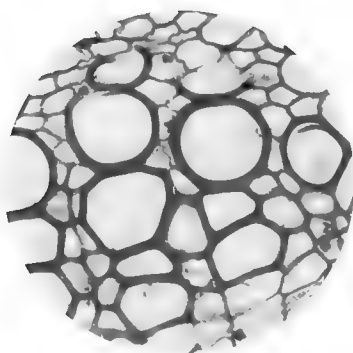
This gives a final magnification of:

Eyepiece lens $\times$ objective lens $\times 2$ Note this figure.

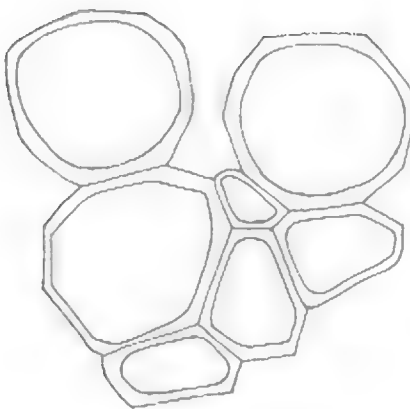
If the eyepiece lens is $\times 10$, and the objective lens is $\times 10$, then:

Final magnification = $10 \times 10 \times 2$ (drawing is about twice the size of the specimen) = $\times 200$ magnification

So if this is what you can see:
(with $\times 100$ magnification)



and this is what you have drawn:



continued

- ▼ Now examine the prepared slide of the wall of the mammalian small intestine in cross section (T.S.) under medium ($\times 10$) objective lens. How many tissue layers can you identify in this specimen?
- ▼ Make a plan drawing of this specimen; do not show individual cells, just tissue layers. Label the different tissues and annotate your labels.
- ▼ Calculate the final magnification of your drawing
- ▼ Re-examine the prepared slide of T.S. leaf. Locate the palisade cells just under the upper epidermis using the medium power ($\times 10$) objective lens, and focus under the high power ($\times 40$) objective lens to do your drawing.
- ▼ Draw 2-3 adjacent palisade cells (at least a few cm across), and label the structures you can identify. These may only be the cell walls, and the chloroplasts which are pushed up against them. Annotate your labels.
- ▼ Calculate the final magnification of your drawing and record it.
- ▼ Re-examine the prepared slide of T.S. small intestine under the medium power ($\times 10$) objective lens. The epithelial cells are much smaller than plant cells, and are much more indistinct as they lack the cellulose cell wall found in plant cells. You will need to move onto a high power ($\times 40$) objective lens once you have located the column shaped cells on the inner edge of the intestine wall; with their 'brush' borders of microvilli. Mucous secreting goblet cells will also be visible.
- ▼ Draw 2-3 cells (not too small), label the structures you can identify, and annotate your labels.
- ▼ Calculate the final magnification of your drawing and record it.
- ▼ Make sure all drawings have suitable headings.

Teaching Notes

With plant tissues the student can usually see the cell walls and chloroplasts, the vacuole and nucleus. However, the cells can be quite badly distorted, poorly stained, and therefore difficult to draw. It might be a good idea for students to draw xylem elements in T.S. to gain some experience in drawing plant cells.

In the much smaller epithelial cells the nuclei should be seen, but they often overlap each other. The microvilli appear as a narrow layer along the free edge of the cells.

(It is interesting to note that many organelles were first described using the light microscope (some over 100 years ago) e.g. Golgi body (apparatus), mitochondria, and endoplasmic reticulum).

This practical also provides an opportunity to discuss the main points of **biological drawing technique**.

The important points to get across are:

- ▼ Drawings should be line drawings, with no shading, or use of colour.
- ▼ They should be large enough to be clear.
- ▼ The lines should not be sketchy.
- ▼ Pencils should be sharp, HB or H.
- ▼ Label lines should be drawn with a ruler, and should not cross. The labels should be written in pencil, and should be well away from the drawing.
- ▼ Labels should be annotated, either next to the label or as a suitable note, to give further information as required.
- ▼ Magnification, or an indication of size/scale, should be included.
- ▼ Drawings should be clearly labelled with the student's name, the name of the specimen, its classification if appropriate, type of section / squash etc., and preparation or staining details.
- ▼ Sometimes, depending on the microscope and the slide, the plant cell wall cannot be clearly seen to have a thickness, but it is always drawn with a double line to distinguish it from membranes.

Requirements per student

Microscope
Drawing materials
Prepared slides of T.S. leaf
Prepared slides of T.S. mammalian small intestine

Safety considerations

There are no special safety considerations for this practical, other than the safe use of the microscope.

Unit 1:

Molecules and Cells

1.3 Cellular Organisation

Practical work should include the use of a suitable graticule to make measurements

Use of a suitable graticule to make measurements and understand the concept of scale in relation to drawings done from specimens seen using the light microscope

Introduction

There are two methods you can use to measure the size of objects under the light microscope.

One is to use an eyepiece graticule, which will need to be calibrated for your microscope using a stage micrometer. This will give you a an accurate measurement, but the procedure is complex.

A simpler way of understanding the concept of scale in relation to drawings is based on the magnification as calculated previously.

Method I - Use of the Eyepiece Graticule

- ▼ An eyepiece graticule is a scale put in your eyepiece lens, so that it can be seen when you look down the microscope. These scales are usually on small circular pieces of glass or acetate.
- ▼ To insert the scale in your eyepiece, remove the eyepiece lens from the microscope, and carefully unscrew the top lens. If you look down into the lens body, you should see a ledge running round the sides about halfway down. Drop the scale into the lens body, so that it rests on the ledge, then replace the top lens. It does not matter if the scale is the wrong way up, but if it annoys you, unscrew the lens again and turn the scale over.
- ▼ When you look through the microscope, you should see the scale overlying your specimen.
- ▼ To calibrate the scale, you need to use a stage micrometer. This can be a special slide with a scale engraved on it, or one can be made by mounting a scale on a slide under a coverslip using Canada Balsam. It usually consists of a scale 1 cm long, which is divided into 100 units, each of which is 0.1 mm (100 μm), there is an extended line every 10th unit. It is worth being aware that these scales can be badly scratched.

To calibrate the eyepiece scale

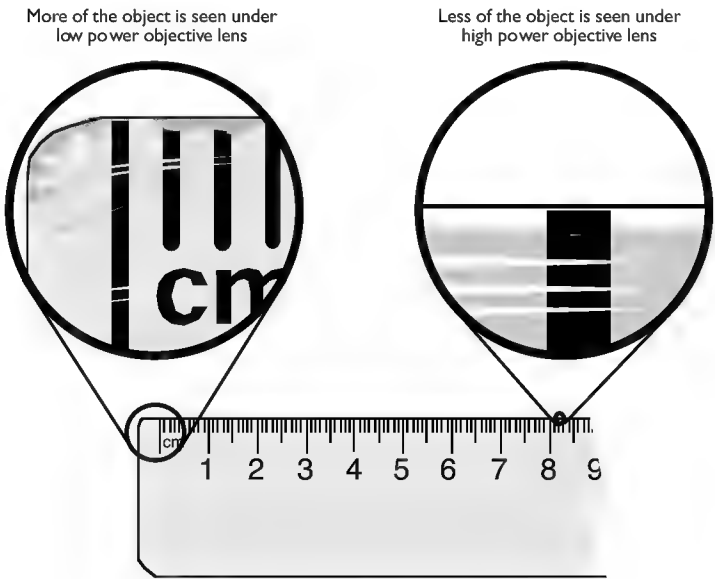
- ▼ Place the stage micrometer on the microscope stage and hold it down with the clips.
- ▼ Using the eyepiece lens with the scale in, look through the microscope and focus it so you can see both scales clearly. This is usually easier if you focus your eye on the eyepiece scale and adjust the microscope so the stage scale comes into focus as well.

continued

- ▼ Move the stage micrometer carefully so that the starting units of the two scales coincide.
- ▼ Count along the two scales until there is again a coincidence between the two scales. Note down the number of divisions along each of the two scales that this represents.
- ▼ As each division along the stage micrometer scale represents 100 µm, then:
$$\text{1 division on the eyepiece scale (in mm)} = \frac{\text{Number of divisions on the stage micrometer scale}}{\text{Number of divisions on the eyepiece graticule scale}} \times 100$$
- ▼ At x100 and x400 magnification the lines on the scale will have a definite thickness. It is important to measure from one side of one scale mark, to the same side of the next coinciding mark.
- ▼ This procedure should be done for all the objective lenses on your microscope, so that you have a scale calibration for all possible magnifications. Record this information in a table with the following headings.

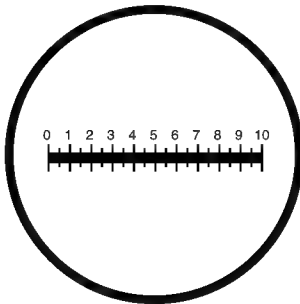
Power of lens	Magnification	Eyepiece scale 1 division (in mm)

- ▼ When you measure another specimen, you will already have the calibration figures, so all you have to do is count how many eyepiece scale divisions your specimen covers, and multiply that by the calibration factor for that objective lens.

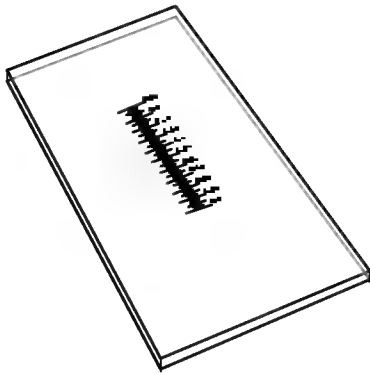
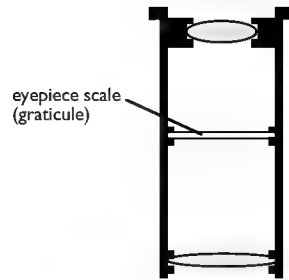


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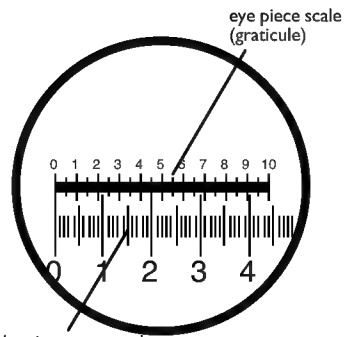
Eyepiece scale (graticule)



Eyepiece scale as seen when held up to the light away from the microscope.



Scale in mm etched upon a microscope slide or a printed acetate sheet (slide micrometer)



slide micrometer scale

Accurate measurements can be achieved using the two scales in combination through the lenses of the microscope.

Method II - Using the Magnification to Estimate Size

Repeat the procedure to determine the final magnification of your drawing of a specimen.

To work out the size of the original object under the microscope, measure a line across your drawing in mm, and divide it by the total magnification, giving the answer in μm .

Teaching Notes

Individual help is often required to ensure that students fully understand the procedure of using the eye piece graticule.

The plastic ruler analogy may help, and by giving an estimate of the diameter of the field of view can even provide a crude measure of size of microscopic structures seen under the light microscope.

The accuracy of the technique could be checked by measuring structures of known and consistent size, e.g. red blood cell (6-8 μm).

Requirements per student

Microscope
Eyepiece graticule
Slide micrometer
Suitable prepared slides

Safety considerations

There are no special safety considerations with this practical, other than the safe use of the microscope.

Unit 1:

Molecules and Cells

1.4 The cell cycle

Practical work to include preparation and staining of root tip squashes to recognise and study stages in mitosis using a light microscope

Preparation of an onion root tip squash to demonstrate stages in mitosis using a light microscope

Introduction

An onion root tip is to be used to show the stages of mitosis in the dividing cells. The tip will need to be softened so the cells can be squashed to spread the chromosomes in one plane, and the chromosomes stained to see the stages of mitosis.

Method

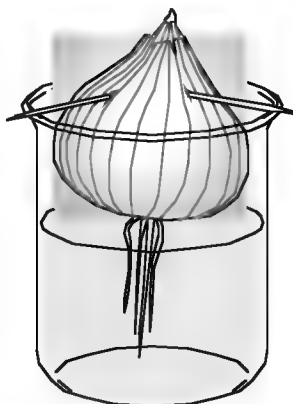
- ▼ Remove a root from a growing onion bulb. Carefully cut about 0.5 cm from the tip of the root, making sure it is the tip end, not from the end near the onion. (It should be slightly pointed)
- ▼ Place the root tip in a watch glass. Add 9 drops of acetic orcein stain, and 1 drop of molar hydrochloric acid. Heat the watch glass gently, using a hotplate or spirit burner, or by passing it carefully but quickly through the flame of a bunsen burner: **DO NOT LET IT BOIL!** Keep the watch glass hot but not boiling for 5 minutes: if you have to hold it, use forceps.
- ▼ Place the root tip on a clean slide, and add a drop of 45% ethanoic acid. Cut away all but the terminal 1mm. Cover with a clean coverslip.
- ▼ Squash the root tip gently using a pencil: hold the pencil vertically just above the coverslip, then let it fall through your fingers onto the coverslip. Repeat this 2-3 times. This should spread the cells out under the coverslip so they can be examined under the microscope.
- ▼ Examine the slide under the microscope, under the medium power (x10) object lens, then using the high power (x40) objective lens. Identify the various stages of mitosis, and make annotated drawings of each stage.
- ▼ Record the final magnification of your drawing.

Teaching Notes

Growing the onion roots needs to be started 6-7 days before the practical. It is best to use onion sets from a garden centre, or locally grown onions, as some onions bought from a supermarket have been treated to prevent sprouting.

Push two cocktail sticks through the onion at right angles: these will support the onion in the beaker, as shown in the diagram. Fill the beaker with water until it just covers the root area of the onion, and leave it in a cool place until the roots have sprouted. They do not have to be kept in the dark. Ideally, the roots need to be about 2 - 5 cm long.

If the onions are ready before the lesson is due, or if you wish to harvest onion roots and store them until needed, they can be treated with Carnoy's solution (6 parts absolute ethanol: 3 parts chloroform: 1 part glacial acetic acid) for 24 hours, then stored in 70% ethanol until needed.



The watch glasses need to be heated gently for five minutes, but they should not be allowed to boil or dry out. If they begin to dry out, an extra drop of stain can be added.

If the students have trouble finding mitotic cells in their specimen, check that they have actually used the root tip: if you can see developing xylem or phloem, they have retained the wrong portion.

It can be useful to have a few prepared slides of root tip squashes or sections, in case the students have difficulty with the slide preparation. Appropriate photographs and/or diagrams will also be useful. In addition, it will be useful if the students can see video footage of mitosis. It is important to make it clear that mitosis is a continuous process, which is subdivided for convenience.

It might be possible for the students to estimate the relative length of each stage of mitosis, by counting how many cells they can see which are in each stage.

continued

Requirements per student

Watch glass
Forceps
Slide and coverslip
Bunsen burner/spirit burner
scalpel/knife
Microscope

Requirements for class

Growing onions: see previously
Acetic orcein stain in dropping bottles
1 molar hydrochloric acid in dropping bottles
45% ethanoic acid, in dropping bottles
Adjustable hotplate, if available
Beaker of detergent for the used slides

Book illustrations, photos etc.

Safety Considerations

The Acetic orcein stain, ethanoic acid and the 1 molar hydrochloric acid all need to be treated with care, as they are corrosive. You may want to provide disposable gloves for the students.

Use of dropping bottles for the staining compounds makes the practical safer.

Care is needed with heating the watch glass: a spirit burner or adjustable hotplate is better, but a bunsen burner can be used if necessary. The students should just pass the watch glass through the roaring flame, turned down low.

Unit 2B:

Exchange, Transport and Reproduction

2B.1 Exchanges with the Environment

Practical work should include the use of simple respirometers.

An experiment to investigate the rate of respiration of small organisms or living tissues using a simple respirometer

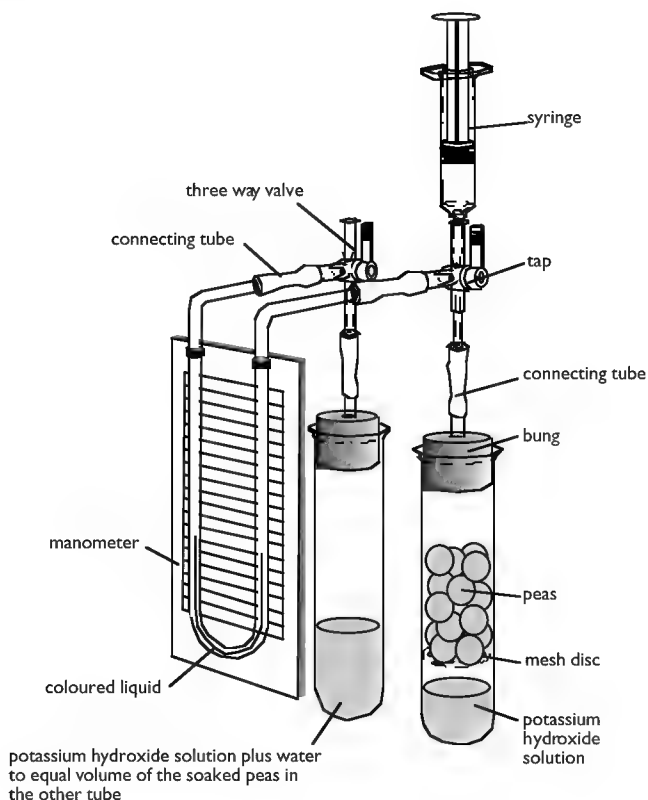
Introduction

A respirometer is an apparatus used to study respiration, rates of respiration and respiratory quotients in whole organisms, e.g. soaked, germinating seeds such as peas; small animals, e.g. woodlice, mealworms, blowfly larvae, earthworms and locusts; and microorganisms, e.g. yeast.

The principle of the apparatus is that the organisms respire in a closed chamber, oxygen is taken up and an equal volume of carbon dioxide is given off. The carbon dioxide is absorbed by a carbon dioxide absorber (e.g. potassium hydroxide), the volume of gases in the chamber decreases, and the proportional decrease in pressure can be measured by a manometer.

- ▼ To measure the rate of respiration (to obtain a quantitative result), the oxygen uptake over a certain period of time is measured.
- ▼ The potassium hydroxide solution (or soda lime pellets) absorbs the carbon dioxide produced by the organism, as the pressure within the apparatus falls the liquid in the manometer moves towards the chamber with the living organisms.
- ▼ The rate at which the liquid moves towards the chamber is equivalent to the rate at which the organisms are taking up oxygen (rate of aerobic respiration).
- ▼ The air in the experimental tube is sensitive to changes in temperature, and these changes could interfere with volume and pressure changes due to the respiration of the organisms. Therefore a second tube is attached to the other side of the manometer which acts as an 'equalising chamber' and compensates for any changes in volume and pressure within the experimental tube as a result of changes in external temperature. Any change of external temperature will affect both tubes equally so any effect on the chamber containing the organisms is cancelled out.
- ▼ A control apparatus should also be set up which contains inert (non-reactive) material or dead organisms equal in mass to the living organisms in the experimental apparatus. This is necessary to demonstrate that any changes in the fluid level in the manometer of the experimental apparatus is due solely to the respiration of the living organisms.
- ▼ (One control apparatus may be sufficient for the whole group. If you are setting up a control, you will need the same apparatus as below, but with an equivalent mass of dead organisms, e.g. boiled, cooled peas, or inert material, in the experimental tube).

continued



- ▼ Both sets of apparatus should be set up in a water bath, with the manometers positioned over the edge so that they are not in the water. Water is less prone to changes in temperature than air, and the water bath allows a constant temperature to be maintained throughout the experiment. It also enables the temperature to be changed if the effect of temperature on the rate of respiration is to be investigated.

In this experiment the rate of respiration of a living organism will be investigated.

The affect of temperature on the rate of respiration can also be investigated.

Method

HANDLE THE MANOMETER VERY CAREFULLY as the column of coloured fluid easily breaks up (in fact you will be doing very well if it doesn't).

- ▼ To the experimental boiling tube add about 5 cm³ of potassium hydroxide solution (or a known mass of soda lime pellets). Insert the mesh disc and add a known mass of soaked peas (the peas must not come into contact with the chemical)

continued

- ▼ To the second boiling tube (the thermobarometer or compensating tube) add the same volume of KOH solution or mass of soda lime pellets used before PLUS some distilled water equivalent to the volume of the soaked peas and the mesh disc in the experimental tube.
- ▼ Firmly push the two rubber bungs into the boiling tubes, and very carefully insert the manometer into the appropriate connectors on the plastic taps inserted in the rubber bungs (it may be necessary to grease these connections).
- ▼ Make sure the taps are both in the 'open to the air' position.
- ▼ Very carefully transfer the apparatus to a water bath, tubes inside and manometer outside.
- ▼ Allow the apparatus to come into equilibrium at 20°C for about 10 minutes.
- ▼ Turn the plastic taps to the 'air to manometer' position.
- ▼ Set the syringe at 0.5 cm³ and insert it into upper part of the plastic tap above the experimental tube.
- ▼ Use the syringe, very carefully to adjust the levels of the manometer fluid, so it is equal in the 2 arms. Note the position of both fluid levels and the new reading on the syringe.
- ▼ Turn both plastic taps to the 'manometer to boiling tube' position.
- ▼ The apparatus should now be ready to use.
- ▼ Record the position of the manometer fluid at about 2 minute intervals for 16 minutes (But watch carefully and be prepared to change your timings according to what is happening in your experiment). Record your results.
- ▼ At the end of your first set of readings - adjust the tap above the experimental tube to the 'air to manometer' position and very carefully use the syringe to reset the position of the manometer fluid and note the new syringe volume. If possible repeat your readings for a second and third time and record your results.
- ▼ Look at the control experiment and record the results.
- ▼ If you are able to continue your procedure to investigate the effect of temperature on the respiration rate, increase the temperature of the water bath to 30°C. Allow the apparatus to equilibrate at the new temperature, reset the manometer fluid with the syringe, and repeat your readings, and record your results
- ▼ Increase the temperature to 40°C or drop it to 10°C, and repeat your readings and record your results. (With invertebrate specimens you would probably restrict the temperatures to between 10 - 20°C.
- ▼ Work out the volume of O₂ consumed/hour:
$$\text{O}_2 \text{ consumed} = \text{Volume of O}_2 \times 60 / \text{Time in mins} \times \text{mass of living organisms (g)} = \text{cm}^3 / \text{g} / \text{hr}$$

Plot a graph of volume of oxygen consumed/time

Analyse all your results, including those from the control experiment, write your conclusions, and note any improvements you would make in the method used.

Teaching Notes

This experiment can be disappointing if the fluid does not move, or even worse, moves in the 'wrong' direction. Students must be ready for this and be prepared to check the apparatus and keep resetting the manometer fluid etc.

It is suggested students work in pairs because some of the manoeuvres are quite difficult.

You may not have the apparatus described.

However the method used does cover all the main principles involved in the use of any Respirometer. Detailed instructions will be included by any supplier for use of their particular design of apparatus.

It is suggested that the manometers are half filled with fluid before the lesson starts, as to get the fluid in place without air bubbles, can waste a lot of valuable time. There are complicated ways of introducing the fluid, but usually with care it can be done with a syringe.

One control experiment will probably be enough for the whole group.

Timing of readings should be varied according to the conditions on the day, e.g. type of organism used.

It may not be possible for everyone to investigate the effect of temperature on respiration rate, during the same lesson, but if a few pairs of students have the experiment working well, they could investigate different temperatures and then results can be distributed to the group as a whole.

The volume of O_2 consumed per hour could be calculated:

O_2 consumed per hour = Volume of O_2 x 60/Time in mins x mass of living organisms (g) ($cm^3/g/hr$)

A graph can be plotted Volume of O_2 consumed/time

A graph can be plotted Volume of O_2 consumed/time, for different temperatures

Calculate Q_{10} - how does the rate increase for a $10^\circ C$ rise in temperature

Q_{10} = Rate of Respiration at $T + 10^\circ C$ / Rate of Respiration at T

The Respiratory Quotient (RQ)

$RQ = CO_2 \text{ evolved} / O_2 \text{ consumed}$

The RQ is obtained using the apparatus described above with water instead of KOH.

If the manometer meniscus does not move, the volume of CO_2 being evolved is the same as the volume of oxygen being absorbed, and the $RQ = 1$

If the manometer meniscus moves away from the seeds more CO_2 is being evolved than oxygen consumed and the $RQ = >1$

If the manometer meniscus moves towards the seeds more O_2 is being absorbed than CO_2 is being evolved, and the $RQ = <1$

It is possible to compare the RQ of seeds soaked for different lengths of time or containing different food reserves.

continued

Requirements for each student

Manometer and manometer fluid (**Sudan III** in paraffin oil/Brodie's fluid)
Two bungs fitted with connecting tubes and adjustable plastic taps (or connecting tubes with rubber tubing and 2 screw clips)
Thermostatically controlled water bath or large beaker, tripod, gauze and Bunsen burner.
Two boiling tubes and 1 mesh basket/disc
Thermometer
Spatula
Stopclock
Balance
25 cm³ measuring cylinder
1 cm³ syringe (a larger one can be used but this will probably have to be supported)
Ice cubes if necessary
Vaseline
15% KOH solution / Soda lime pellets
Distilled water
Specimen material, e.g. peas soaked for 24 hours.

For 1 control experiment

Similar apparatus
Boiled cooled peas

Safety Considerations

Soda lime should not be handled
15% KOH is caustic
Usual care when using living material.

Unit 2B:

Exchange, Transport and Reproduction

2B.2 Transport Systems

Practical work to include demonstrations and measurements of transpiration using a potometer.

Demonstrations and measurements of transpiration using a potometer

Introduction

Transpiration can be measured using a potometer. The principle of which, is that as the water evaporates from the leaves of a shoot, water is pulled up the shoot by the cohesive pull of the transpiration stream, and an air bubble is drawn along a capillary tube at the same rate - thus giving a measure of the rate of transpiration.

The time taken for the air bubble to travel a certain distance, or the distance travelled in a certain time, can be recorded and the rate of transpiration calculated.

If placed on a sensitive electronic balance, the loss of mass represents the loss of water by transpiration from the leaves.

If a set of consistent results is obtained, the figures of the uptake and of the loss of water, can be compared.

Method

- ▼ The potometer is filled by immersing it totally in water, preferably freshly boiled and cooled water which has no air bubbles.
- ▼ The shoot to be used should be cut from the plant under water, to prevent any air bubbles entering the xylem elements, and kept under water until it is inserted into the apparatus
- ▼ All joints in the apparatus should be well vaselined to prevent any leaks, which would invalidate the results by reducing the apparent rate of transpiration.
- ▼ After setting up, but before allowing air to be drawn into the capillary tube, the apparatus should be allowed to come into equilibrium, with the end of the capillary tube being kept under water until such time as an air bubble is introduced.
- ▼ An air bubble is introduced by lifting the capillary tube out of the water to allow air to be drawn up, and then returning the tube to the water.
- ▼ The time it takes for the bubble to travel a set distance along the tube is then recorded.
- ▼ After the bubble has travelled a certain distance, it is returned to the beaker end of the tube by running water in from the reservoir.
- ▼ The procedure is repeated until some consistent results are obtained.

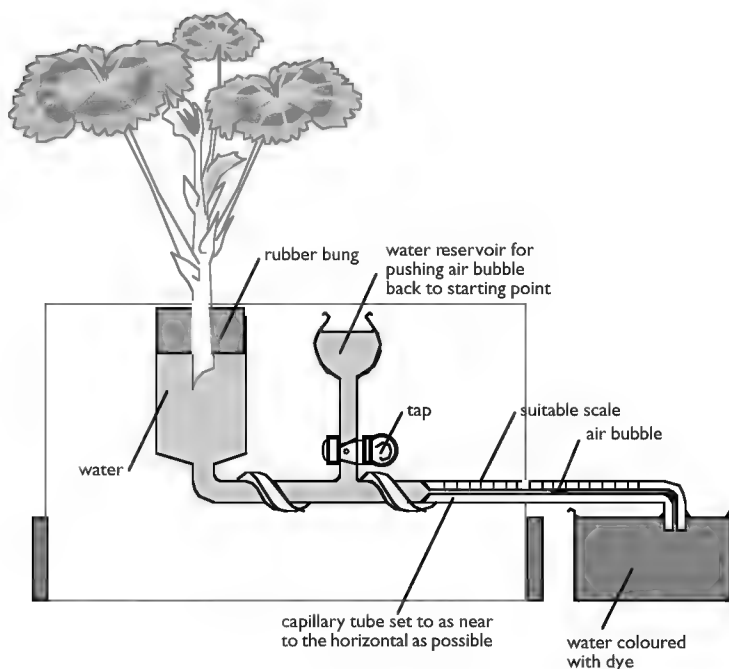
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- ▼ If the calibration on the capillary tube is in millimetres, and the diameter and hence the radius of the tube is known, then the volume of water taken up can be calculated using the formula:

$$\pi r^2 \times \text{distance travelled by bubble} = \text{volume of water uptake}$$

Sometimes, however, the calibrations are already in units of volume, for example mm^3 or cm^3 (ml).

Express the results as either cm^3 per minute, cm^3 per hour, or cm^3 per hour per cm^2 of leaf area.



Teaching Notes

The experiment is often run without a bubble, just with the end meniscus as the point of measurement. Strictly speaking this is less valid than using a bubble, as it is possible for water to evaporate from the open meniscus, thus increasing the apparent rate of water uptake - although in reality the effect is immeasurable.

The potometer actually measures the rate of water uptake, which under these experimental conditions is not the same as the transpiration rate. In this experiment the cross sectional area of the cut shoot is not as large as the equivalent area of root hairs that would normally supply the leaves, therefore the rate of uptake is less than the rate of transpiration.

Lengthy attempts to set up a whole plant complete with its root system in a potometer, in order to increase the rate of movement of the meniscus, and overcome the problem of the cut stem not providing enough surface area for water uptake, all failed for unknown reasons.

If set up successfully the apparatus can be used to compare rates of transpiration in different environmental conditions. e.g. still air and moving air (possibly using a hair dryer or fan).

The apparatus could also be set up with different leaf surfaces greased.

Given ideal results, it would be found that the loss of water as determined by placing the apparatus on an electronic balance for the duration of the experiment, is greater than the amount of water uptake as determined by the movement of the bubble.

Requirements per group

Potometer set up and ready to go
or
Potometer
Vaseline
100 cm³ beaker, water and dye
Large sink
Suitable leafy shoot cut in the correct way, and to fit the apparatus
Hair dryer or fan if required

Safety Considerations

There are no special safety considerations for this experiment, only the normal precautions with the cutting of the shoot and using the hairdryer or fan.

Unit 2B:

Exchange, Transport and Reproduction

2B.2 Transport Systems

Practical work to include stomatal counts.

Stomatal counts

Introduction

Stomata can be observed directly with reflected light.

Epidermal strips can be peeled from some leaves, mounted on a slide and viewed with transmitted light.

Clear nail varnish can be used to make an imprint of the leaf surface, so you can see the stomata layer without having to peel off the leaf epidermis.

Method

- ▼ Paint a small amount of clear nail varnish on the upper and lower surfaces of a variety of leaves (about 1 cm square in each case), e.g. privet, holly, laurel, dandelion and grass.
- ▼ Allow the nail varnish to dry thoroughly, then carefully peel the layer of nail varnish off the lower surface, using forceps.
- ▼ Place the layer of nail varnish on a microscope slide in a drop of methylene blue, and make sure it is lying flat. Place a coverslip over the nail varnish layer.
- ▼ Examine the lower epidermis varnish layer using the low power ($\times 10$) objective lens of the microscope. Identify the stomata and guard cells on the leaf surface. Count how many stomata you can see in the field of view of the microscope. Then move the microscope to another area of the layer and count how many stomata are visible.
- ▼ Repeat the count five times, and calculate a mean number of stomata per field of view.
- ▼ Measure the diameter of the field of view with a stage micrometer and calculate the number of stomata per mm^2 of leaf surface.
- ▼ Repeat the process with the upper epidermis varnish layer, and calculate the number of stomata per mm^2 of leaf surface.
- ▼ Explain how your calculations relate to the results of your investigation with the potometer.

Teaching Notes

It may be easier to peel the nail varnish films off under water.

If there is a problem with air bubbles and folds in the nail varnish film, try peeling the film off onto the coverslip, and dropping the slide onto the coverslip (the method used in Pathology labs when making slides)

Requirements per student:

Clear nail varnish

Forceps

Microscope

Slide and coverslip

Methylene blue in a dropper bottle

Supply of freshly cut leaves; privet, holly, laurel, dandelion and grass

Safety Considerations

There are no safety considerations for this experiment.

Unit 2B:

Exchange, Transport and Reproduction

2B.2 Transport systems

Blood and body fluids:

Practical work to include the microscopic examination of stained blood films and the identification of cells.

The microscopic examination of stained blood films and the identification of cells

Introduction

Red blood cells are one of the smallest cells you will view under the light microscope, and although the smear is large enough, care still has to be taken to find the focus with the high power (x40) objective lens. The nuclei of white blood cells stain dark blue and when present in the smear are easily seen, however, they are few and far between, and you may need to look at a number of fields of view to find examples of the different types of white cell. They are usually easier to spot under the medium power (x 10) objective lens, you can then move to high power (x40) objective lens to draw the cells.

Method

- ▼ You are provided with a prepared slide of a human blood smear. Examine it under the microscope using the medium power (x 10) objective lens, and then high power (x40) objective lens.
- ▼ Identify the various types of blood cell: red cells, granulocytes, lymphocytes, and monocytes.
 - Granulocytes 72% (Lobed nucleus and granular cytoplasm)
 - Lymphocytes 24% (Large circular nucleus fills most of the cell).
 - Monocytes 4% (Larger cell with large kidney shaped nucleus).
- ▼ Draw examples of each type of cell, label them and annotate your drawings with details of their functions.
- ▼ Record the final magnification of your drawing (eyepiece x objective x size difference), near the title of the drawing.
- ▼ Platelets are usually visible as clusters of small purple 'granules' in the plasma.

Teaching Notes

The nuclei of the leucocytes are stained purple; the cytoplasm is usually pale, with purple or pink-stained granules.

The different types of granulocyte, lymphocyte, and monocyte are found in the following proportions (as % total white cell count)

Granulocytes 72% (70% neutrophils, 1.5% eosinophils, 0.5% basophils)

Lymphocytes 24%

Monocytes 4%

Measurement of the different blood cells would give a good opportunity to use the eyepiece graticule; the diameter of red blood cells is fairly consistent at 6 - 8 μm .

Requirements per student

Microscope

Prepared slide of Human blood smear

Drawing materials

Reference books/photos etc.

Practical Work Sheet 'Measuring specimens under the microscope'

Safety Considerations

There are no safety considerations for this practical, other than the safe use of the microscope.

Unit 2B:

Exchange, Transport and Reproduction

2B.4 Sexual reproduction

Practical work to include an experimental investigation into the factors affecting the growth of pollen grains.

Experimental investigation into the factors affecting the growth of pollen grains

Introduction

The growth of pollen tubes which are normally formed as the pollen grains germinate on the stigma of the flower, can be induced by keeping them in sucrose solution. Various factors that affect the growth of the pollen tube can be investigated.

Method

- ▼ Collect a small quantity of pollen grains from one of the plants provided. Using a paint brush, transfer a few grains to a slide and add a drop of water and a cover slip. View the grains under a microscope with the medium power (x 10) objective lens. Note the distinctive pattern on the surface of the pollen grains. Each type of plant has a characteristic pattern.
- ▼ Transfer another sample of pollen grains into the well of a cavity slide. Add 2-3 drops of sucrose solution and stir gently with a cocktail stick to ensure the pollen grains are wetted by the solution.
- ▼ Put your slide in an incubator at 25°C, and leave the pollen grains to germinate. Remember to top up the sucrose solution (with sucrose solution at 25°C) if the slides start to dry up.
- ▼ Examine the slide at 15 minute intervals. It may be quite a long time before the pollen tubes appear, and you may be provided with pre-prepared samples if your time is short.
- ▼ Once the pollen tubes have formed put a coverslip on and irrigate the slide with acetocarmine or neutral red to stain the nuclei (pollen tube nucleus and male gametic nuclei).
- ▼ Continue to incubate and observe every 15 minutes, note the time at which the pollen tubes are at least as long as the width of the pollen grain.
- ▼ Working in a small group, identify factors that you think might affect the growth of pollen tubes, either positively or negatively. Devise investigations to test your predictions. Decide how you are going to measure the growth of the pollen tubes.
- ▼ Check your plans with your supervisor, then carry out your investigations.
- ▼ Report on your findings.

Teaching Notes

This practical should provide a good potential extension exercise for your more able students, who might try some of the more complex factors, such as the presence of stigma extract.

Most flowers will provide some pollen, so use whatever may be available at the time of year. If you are doing this practical during the winter, flowers can be bought from a florist or supermarket. Among the varieties we have tried Lilies work best (other authors recommend *Tradescantia* and *Nasturtium*).

In the summer wind borne pollen grains can be collected on slides coated with glycerine, or sticky tape left in a position exposed to air currents, e.g. a window ledge.

Suggested factors to test are:

temperature;
light levels;
pH;
different concentrations of sucrose;
extract of stigma tissue (prepared by chopping up stigmas removed from the flowers in a few drops of sucrose solution): this could be from the same flower or different ones;
presence of different pollens;
presence of plant hormones.

Requirements per student

Microscopes
Slides and coverslips
Cavity slides and coverslips
Cocktail stick
Paint brushes
Incubator or equivalent
Calibrated eye piece graticules

0.4% sucrose solution, a few cm³ (some recommend as high as 3%)
Acetocarmine stain or neutral red
Plant material, with flowers producing pollen.

Safety Considerations

There are no safety considerations for this practical, other than the safe use of the microscope, unless they arise as a result of the experiments devised by your students.

Unit 2B:

Exchange, Transport and Reproduction

2B.4 Sexual reproduction

Practical work to include making observation on slides of insect testis squash.

Observation of slides of insect testis squash

Introduction

The testis of an insect can be used to identify chromosomes in the various stages of meiosis.

Method

- ▼ Collect a prepared slide of an insect testis squash. This has been stained to show the chromosomes in the cells undergoing meiosis.
- ▼ Examine the slide under the microscope, first using the medium power ($\times 10$) objective lens to identify the stained chromosomes.
- ▼ Under the high power ($\times 40$) objective lens you should be able to see chromosomes in the various stages of meiosis occurring during spermatogenesis. The outlines of the cells will be more difficult to see.
- ▼ Compare what you can see on the slide with equivalent photographs and diagrams, and try to identify as many stages of meiosis as you can (this is not easy).

Teaching Notes

Drawing chromosomes accurately is difficult and may be best omitted.

Requirements per student

Microscope
Prepared slides of insect testis squash
Drawing materials
Reference sources

Safety Considerations

There are no safety considerations with this practical, other than the safe use of the microscope.

Supplementary Practical Work Sheet

Unit 2B:

Exchange, Transport and Reproduction

2B.4 Sexual reproduction

Microscopic examination of the histology of ovary and testis

Introduction

The T.S. of the mammalian testis should be clear, but remember, in cross section, the single coiled semeniferous tubule appears as a collection of apparently unconnected circles.

The L.S. of the mammalian ovary represents a moment in time in the ovarian cycle. Each follicle develops and matures in one position in the ovary, and at any one time several follicles will be caught at various stages of development. A range of slides may have to be examined before all stages are seen. Remember that theoretical diagrams typically show all stages of development of the follicles around the ovary in sequence, even giving the impression that one follicle travels around the ovary during its development.

Keep these points on the interpretation of sections as seen under the microscope in mind, as you examine the slides.

Method

- ▼ Collect a prepared slide of a transverse section (T.S) through the mammalian testis.
- ▼ Examine the slide under the microscope, first using the (x4 or x10) objective lenses, and identify the semeniferous tubules.
- ▼ Next examine a single semeniferous tubule under high power (x40) objective lens, and try to identify the spermatogonia, primary spermatocytes, spermatids, Sertoli cells and developing sperm. The nuclei of cells are clearly seen, but it is often difficult to make out cell boundaries.
- ▼ Using the medium power (x10) objective lens draw a plan of the seminiferous tubules, and using the high power (x40) objective lens make a detailed drawing of part of the wall of one tubule. Compare what you see with photographs and diagrams, and label and annotate your drawings.
- ▼ Now examine the prepared slide of the longitudinal section (L.S.) of the mammalian ovary, using the medium power (x10) objective lens. Identify any developing follicles that are visible. Make a simple low power drawing of what you see. Compare what you see with photographs and diagrams, and label and annotate your drawings.
- ▼ Make sure your drawings have suitable headings.

Teaching Notes

If the mammal from which the slides have been made is identified, try to find out about the pattern of oestrus shown by that animal, as this will prevent the students assuming that there is a monthly cycle in the ovary in question.

Requirements per student

Microscope
Prepared slides of T.S. mammalian testis
Prepared slides of L.S. mammalian ovary (often rabbit)
Drawing materials
Reference material

Safety Considerations

There are no safety considerations for this practical.

Unit 2H:

Exchange, transport and reproduction in humans

2H.1 Exchanges with the environment

Breathing

Practical work to include the use of simple apparatus to estimate vital capacity.

The estimation of vital capacity using simple apparatus

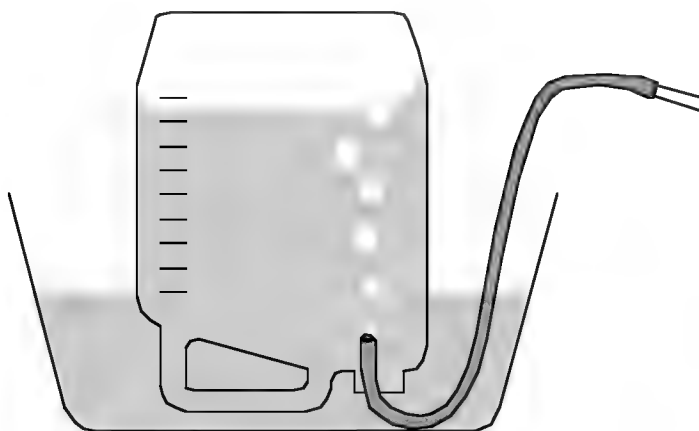
Introduction

SPECIAL SAFETY NOTE

Experiments involving unusual ventilation of the lungs can be dangerous to those suffering from asthma, bronchial disorders of any kind, or epilepsy. Supervisors should be in possession of a Prior Consent Form, and be aware of the status of their subject's health, possible consequences arising from any condition, and the necessary First Aid procedures. The procedures described below are guidelines, the safe implementation of which remains the responsibility of the Supervisor.

Method A - Simple container

- ▼ Collect a transparent container with a single opening, which should have a capacity of at least 6 litres.
- ▼ Using a 500 cm³ measuring cylinder or beaker, measure out 500 cm³ of tap water. Pour this water into the vessel, and, holding the vessel as level as possible, mark the level of the water meniscus using a marker pen.
- ▼ Add another 500 cm³ of water, and mark the new level. Continue adding water in 500 cm³ volumes, until the vessel's capacity is marked off in half-litres to a volume of 5-6 litres.

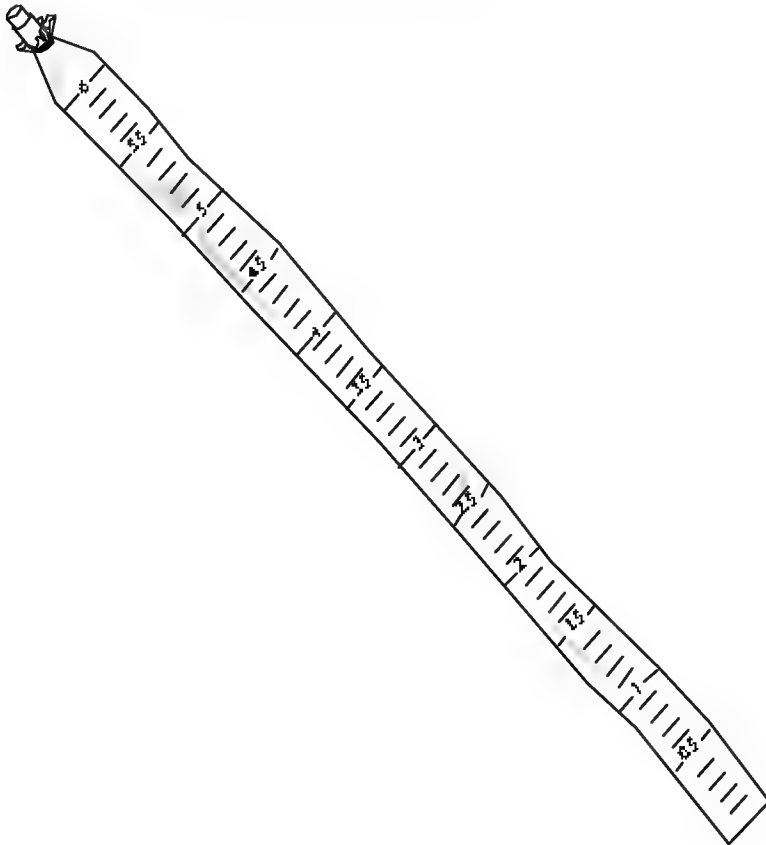


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- ▼ Empty the vessel out into a large sink. Fill the sink with water, then fill the vessel. Place a piece plastic sheet or the screw cap over the open end, and carefully invert the vessel in the sink of water so that it itself remains full of water. Remove the piece of plastic sheet or screw cap.
- ▼ Insert a piece of sterile tubing into the vessel, inhale deeply, and blow your exhaled air into the vessel until you have exhaled as far as you can (making sure that you are not losing any air down your nose), displacing the water from the container. Use the scale you have marked on the vessel to estimate your vital capacity.

Method B - Plastic Bag

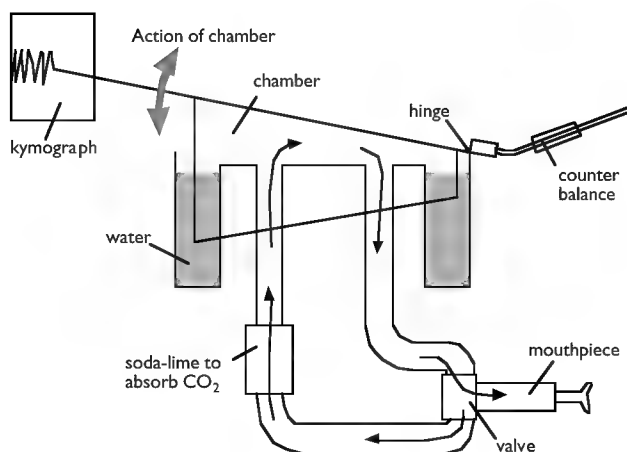
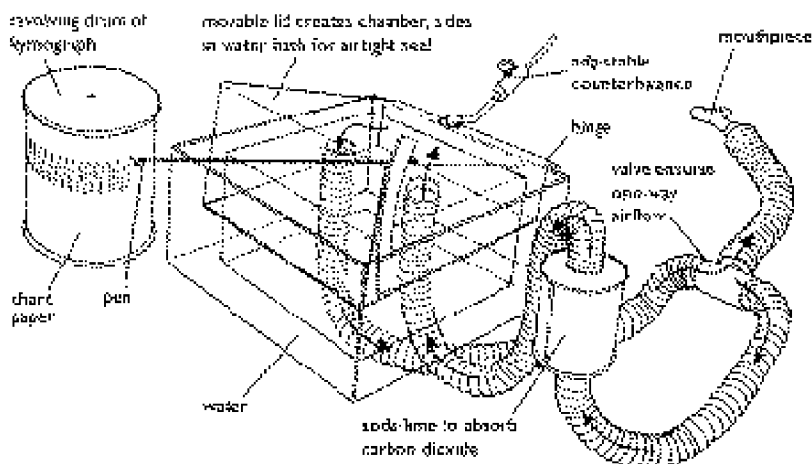
- ▼ Collect a short length of sterile plastic tubing, an elastic band, and a long plastic bag with a sealed end and a scale printed on it.
- ▼ Place the short tube in the open end of the bag, gather the plastic round the tube and hold it in position with the elastic band, making a tight seal.
- ▼ Now inhale deeply, and exhale through the sterile plastic tubing into the bag, breathing out as deeply as you can (making sure that you are not losing any air down your nose). Twist the top of the bag to keep the exhaled air in, and push the air sample down the bag towards the closed end.
- ▼ Read off the estimate of vital capacity from the scale.



Method C - The use of the spirometer (Spirometry)

The Box Type Spirometer. The spirometer commonly used in schools and colleges is of the box type. The apparatus consists of a water-filled tank with a hinged, wedge-shaped float finely balanced over water. The float is hollow with a volume of approximately 9 dm³ (litres) and its lower face is open. The volume of gas enclosed by the water and the top and sides of the float represents the 'breathing mixture'. It is important that the float is perfectly balanced so that it can move up and down freely as a subject breathes the 'breathing mixture'. By using a nose-clip and a well-fitting mouthpiece the subject is isolated from the room air and breathes only from the closed system of the spirometer.

Figure: Box-type Spirometer. When the subject breathes in, air is removed from the chamber, so it moves **down**. When the subject breathes out, air is returned to the chamber, so it moves **up**. These movements are recorded, usually by a pen which is attached to the chamber marking squared paper on a revolving drum (*a kymograph*), or by electronic means.



There is no method provided for this experiment as you must follow the instructions of the Supervisor at all times.

Figures show the kind of traces that are obtained.

Figure: Normal Tidal Breathing trace. Tidal volume and ventilation rate can be determined. If a static exercise can be arranged, e.g. exercise cycle the effect of physical exercise on these measures can be recorded.

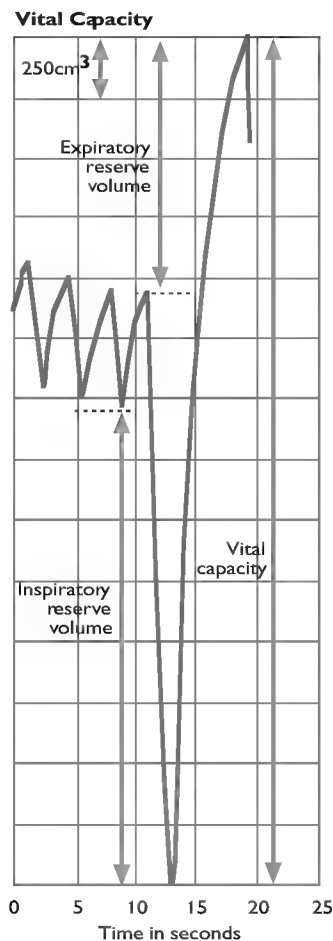
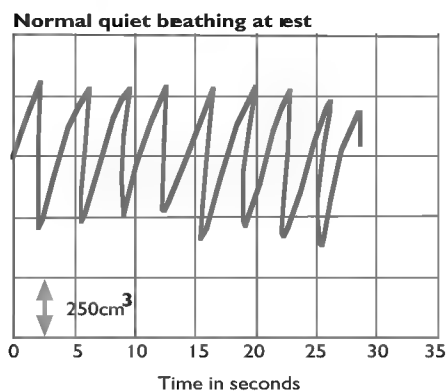


Figure: Vital Capacity Trace. The **vital capacity** is determined by taking a maximum inspiration then exhaling as hard and completely as possible, this can also be referred to as the Forced Vital Capacity (FVC).

Teaching Notes

Three methods are given for this practical, since the equipment available may well vary in different schools/colleges. If you do not have a spirometer, the class should be provided with copies of a sample trace to analyse, since this is a requirement of EDEXCEL (2H.1 Exchanges with the environment. Breathing - *understand the principle of a spirometer and interpret spirometer data.*)

The container method is simple, but since most labs will only have one or two large sinks, it is a slow process if you want the whole class to try it.

The plastic bag can be obtained from Biological suppliers, and the method is simple.

The spirometer should be kept clean, and the breathing hose and non-return valve should be periodically sterilised (*If the valve contains metal parts avoid any chlorine-based sterilants, but give it frequent washes in warm soapy water*).

In order to allow students to accustom themselves to breathing through a mouthpiece there is the option of redirecting the flow of gas so that the room air is breathed, this will not cause the float to move.

Measuring static volumes with the spirometer

It is a relatively simple matter to measure the **tidal volume** (*resting*) and **vital capacity**. If these are measured at rest they are referred to as 'static volumes', as opposed to 'dynamic volumes' which are measured during exercise.

A pen attached to the float will create a trace on a kymograph drum rotating at 1 mm sec⁻¹. It is important that the chart paper is calibrated. This can be done by first allowing the pen to contact the chart paper; then the float can be moved through a distance corresponding to 1 dm³. This movement will translate into a mark on the squared chart paper.

e.g. 1 dm³ = 2 cm (4 squares).

Requirements per student group - Method A

- Simple container
- Large sink
- Screw cap or piece of plastic sheet to cover the opening of the simple container
- Length of rubber tubing with plastic mouthpiece
- Beaker of antiseptic
- Marker pen
- 500 cm³ measuring cylinder or beaker

Requirements per student group - Method B

- Long plastic bag with scale
- Length of plastic tubing and disposable mouthpieces
- Elastic band
- Beaker of antiseptic

Requirements per student group - Method C

- Spirometer and accessories.
- Sterilising fluid

continued

Safety Considerations

Using a box spirometer whilst exercising poses limits on the type and duration of exercise that may be undertaken. Work on a treadmill, or more especially a cycle ergometer, is feasible as the subject can remain relatively still. A greater problem arises from the fact that the spirometer is a closed system and hence the volume of air/oxygen available to the subject is very limited under exercise conditions. The rate at which oxygen can be used during work can be high, therefore the air in the chamber may be replaced, either partially or entirely, with medical grade oxygen (**medical grade oxygen must always be used, as industrial and laboratory grade cylinders are not continuously screened for dust content**). Breathing pure oxygen for a short period of time should have no ill effects as any toxic effects only arise after 12-24 hours exposure. Nevertheless some workers have preferred to limit the oxygen in the breathing mixture to 60% or less. This clearly limits the duration of any exercise carried out, but it definitely errs on the side of safety.

Float Filled with Air. If the float is filled with air, and this is continually rebreathed, the amount of carbon dioxide ($p\text{CO}_2$) gradually increases as oxygen is absorbed by the subject and replaced by an equal volume of carbon dioxide. **This is potentially hazardous, and symptoms can develop within a couple of minutes.** As the level of carbon dioxide increases and the level of oxygen decreases, both the depth and rate of breathing increase, so that the ventilation rate (*rate of breathing multiplied by the depth of breathing*) may rise from about 10 dm³ per minute to up to 50-60 dm³ per minute. Heart rate and blood pressure rise, and mental confusion can set in.

Carbon Dioxide Absorption. If a carbon dioxide absorber is incorporated in the tube returning the exhaled air to the chamber (**'Carbosorb' or 'Indicarb' or a similar grade of self indicating soda-lime granules must always be used, as there is an unacceptable risk of dust from lower grades**), then the $p\text{CO}_2$ in the chamber will not rise, but the $p\text{O}_2$ (and the total volume of air) in the chamber will decrease. This is potentially hazardous. Although the lack of oxygen in the absence of carbon dioxide has little effect on the ventilation rate, the lack of oxygen could lead to loss of consciousness.

Float Filled with Oxygen. If the float is filled with oxygen, and a carbon dioxide absorber is incorporated in the tube returning exhaled gas to the chamber, the volume of oxygen in the chamber decreases in proportion to the volume of oxygen uptake by the subject. This investigation is less hazardous as the $p\text{CO}_2$ is not increasing, nor the $p\text{O}_2$ decreasing. However, all the oxygen can be used up, so a careful watch must be kept on the volume of oxygen left in the chamber as the experiment proceeds.

Length of Time on Spirometer. The question then arises of how long is it feasible for a subject to exercise while breathing the enclosed breathing mixture. This will be determined primarily by the severity of the exercise, the composition of the breathing mixture, and the body size of the subject. Direct measurements of oxygen uptake by college students under conditions varying from standing still to working to exhaustion show a range of values from around 200 cm³ to over 4 dm³ in each minute. Particularly large or well-trained individuals may have even higher minute-by-minute consumptions. It will be appreciated that, given a breathing mixture of 60% O₂, a large subject could undertake heavy exercise for only about 1 minute before exhausting the oxygen supply. Bearing this in mind it is possible to tailor experiments so that during the warm-up to the desired workload the subject might breathe room air (*the spirometer lever would be set to 'atmosphere'*) only switching to the breathing mixture (*lever set to 'spirometer'*) for the test period of 1-2 minutes. There is no reason why the oxygen in the spirometer cannot be topped up during the experiment provided the lever is moved to 'atmosphere' for the operation. The oxygen uptake trace would be interrupted but the test could at least be extended.

Unit 2H:

Exchange, Transport and Reproduction in humans

2H.1 Exchanges with the environment

Breathing

Practical work to include quantitative comparisons of inspired and expired air

Quantitative comparisons of inspired and expired air

Introduction

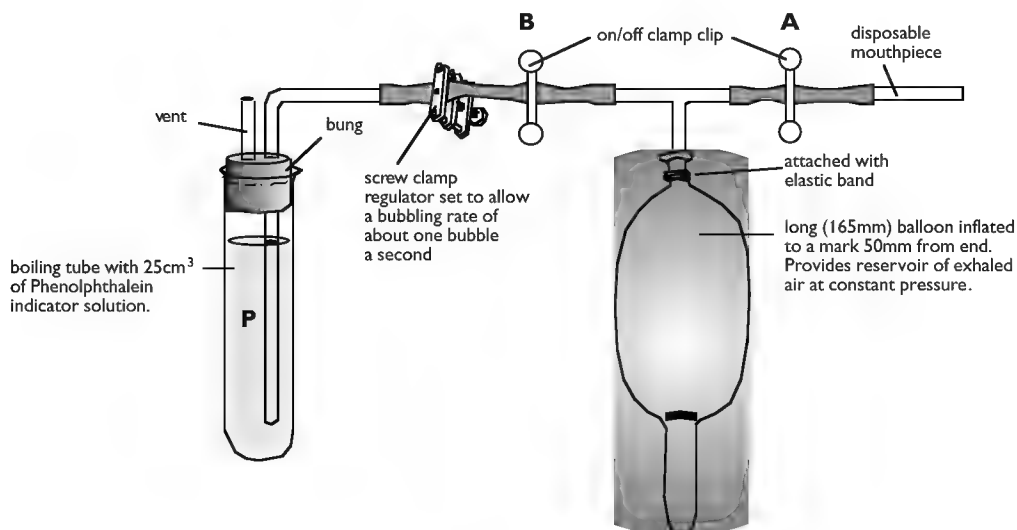
In the simplest investigation using the 'Balloon respirometer' (Method A) the composition of inspired air can be taken as known (being the same as the composition of the air), and the amount of oxygen consumed at rest can be considered to be equal to the amount of carbon dioxide produced:



The 'J-tube Method' (Method B) analyses the oxygen and carbon dioxide content of both inspired and expired air, and the process is more complex.

Method A

Figure: Simple apparatus to determine a measure of the CO_2 content of air



- ▼ Close tap B and open tap A.
- ▼ Inflate the balloon with a small pump attached to the place otherwise occupied by the removable mouthpiece to the mark and close tap A.
- ▼ Open tap B and allow air to bubble through the alkaline indicator solution (*P*). CO₂ being an 'acid' gas will neutralise the solution *P*. Count the bubbles and record the time for the pink colour to disappear. There is only 0.04% CO₂ in air so it is unlikely that the pink colour will disappear. You will have to experiment with dilutions of the alkaline indicator solution and repeat balloon-fulls to achieve a result.
- ▼ Close tap B and open tap A.
- ▼ Inflate the balloon in one breath up to the mark and close tap A.
- ▼ Open tap B and allow air to bubble through the alkaline indicator solution (*P*). CO₂ being an 'acid' gas will neutralise the solution *P*. Count the bubbles and record the time for the pink colour to disappear.
- ▼ As long as care is taken with the rate of bubbling, the time to decolourisation is a crude measure of the relative amounts of CO₂ in the samples.

The apparatus can be used to make simple comparative measures of CO₂ production before, during and after exercise. Samples can be taken at timed intervals throughout the investigation, without disrupting the procedure.

$$\text{The ratio: } \frac{\text{Time to decolour P at rest}}{\text{Time to decolour P after a period of exercise}} = \text{CO}_2 \text{ Index}$$

Plot CO₂ Index and pulse rate against time on the same graph.

Teaching Notes

Quantitative comparisons of inspired and expired air using the 'Balloon respirometer'

Method A

This is a very crude measure, but it gives a quantitative comparison of inspired and expired air that can be achieved with the minimum of apparatus and complicated procedures.

Time spent adjusting the solutions to get a reasonable end point ensures some results.

Even if it is not possible to get the pumped air to change the indicator, the CO₂ content is known (0.04%).

Requirements per set of apparatus

Boiling tube with 25 cm³ of phenolphthalein indicator solution.

Indicator prepared by dissolving 1g of solid phenolphthalein in 500 cm³ of distilled water, and adding Sodium Hydroxide drop by drop until a pink colour is obtained.

Long balloon with a mark to establish a standard volume and pressure of inflation.

The apparatus as illustrated

Disposable mouthpieces

Safety Considerations

The general warnings with regard to experimentation with breathing apply.

continued

Quantitative comparisons of inspired and expired air using a 'J' tube

Method B

In order to compare samples of air, it is necessary to analyse the level of CO_2 and O_2 contained in them. The simplest way to do this is to use a J-tube, which is a hook-shaped length of capillary tubing.

Air is drawn up into the tube, then solutions of potassium hydroxide and potassium pyrogallate are used to absorb the CO_2 and O_2 from the sample.

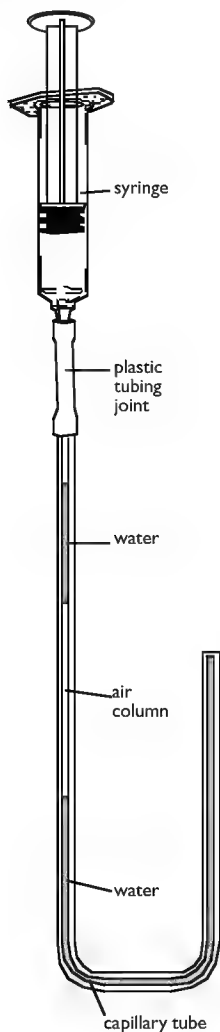
By measuring the amount of sample left it is possible to work out how much CO_2 and O_2 were in the original sample.

In this method, potassium hydroxide solution is used to absorb the CO_2 , then pyrogallol is added to the KOH. This reacts to make potassium pyrogallate within the J-tube, which absorbs the O_2 .

As the procedure requires some practice, and the solutions are toxic and corrosive, this experiment is best performed as a demonstration by the Supervisor.

continued

'J' tube for gas analysis



Teaching Notes

Quantitative comparisons of inspired and expired air using a 'J-tube'

Method B

This practical is fiddly, but it works quite well.

The most difficult aspect is getting used to the tiny amounts of pressure needed to move the air column: it is suggested you spend a couple of minutes working with the air column and water seals, before starting to use the more toxic substances.

The air column should be between 100 and 200 mm long. Much shorter columns do not give very measurable changes in length, and longer ones can be difficult to handle. When moving the air column back and forth, it should not be allowed to get up as far as the air / water space inside the syringe.

An outline method is set out below, but should be practised a few times and modified if necessary in the light of your experience.

▼ Label 4 small beakers a, b, c, and d. Wearing gloves and safety glasses, fill the beakers from one quarter to half full with the following materials:

- a) Water
- b) Potassium hydroxide (KOH - for absorbing carbon dioxide)
- c) Pyrogallol (for absorbing oxygen)
- d) Dilute hydrochloric acid (for cleaning the J-tube)

▼ Push the plunger of the syringe fully into the barrel. Draw a small quantity of water into the J-tube (about 5 cm long), then draw up approximately 10 cm length of air, then draw up some more water. This creates a sample of normal atmospheric air that can be analysed. Practice pushing the air column back and forth for a couple of minutes, until you have got the hang of the amount of pressure needed, the syringe movement will be tiny!

▼ Wait for at least 1 minute, and do not handle the capillary tubing where the air column is positioned. Measure the length of the column of air in millimetres and note it down (length A).

▼ Expel all but about 1 cm of the water from the open end of the J-tube, keeping this 1 cm to maintain a seal for the air column. Place the end of the tube in the potassium hydroxide solution and draw up a quantity of the KOH. Keeping the end of the tube in the KOH, push the air column back and forth in the J-tube, by using the syringe plunger, about 6 times, allowing the air column to come into contact with the sides of the tube wetted with the KOH solution. This will absorb the CO_2 from the air column. Remembering not to handle the capillary tubing, wait one minute, then re-measure the length of the air column and note down the new length (length B).

▼ Now expel all but 5 cm of the KOH from the J-tube. Place the end in the pyrogallol solution and draw up a sample. Push the air column back and forth in the J-tube as you did with the KOH, but DON'T expel the hydroxide. The KOH and the pyrogallol will react in the tube to form potassium pyrogallate, which will then absorb the O_2 . Wait for 1 minute, then measure the length of the air column again (length C).

continued

- ▼ Expel all the contents of the J-tube into the sink and wash them away with water. Then wash the J-tube out thoroughly, first with water, then with dilute HCl, then with water again.
- ▼ Place a large test-tube in a bowl of water. Allow it to fill up with water, then raise it up to a vertical position, with the open end down, so it remains full of water. (See Diagram)
- ▼ Bend a clean bendy-straw, and place the bent end into the bowl of water and exhale into the straw from the straight end. As you get close to the end of your breath, place the test-tube over the bent end of the straw, and collect a sample of your exhaled air in the test-tube. It is best to collect a sample of air from as deep in your lungs as possible, so you should wait until you are almost out of breath.
- ▼ Keep the test-tube in the water to hold the sample of air in the tube. Draw up about 5 cm of water into the J-tube, then insert the end of the J-tube into the test-tube and move it up until the end is in your air sample. Draw up about 10 cm of your expired air sample, then about 5 cm of water to seal the sample.
- ▼ Test the sample of air using the KOH and pyrogallol in the same way you did before, and note the lengths of the column at each stage.
- ▼ If you have time, carry out some vigorous exercise for 3-5 minutes (for example run on the spot) then immediately, before you get your breath back, produce another sample of exhaled air in the same way you did in steps 6-8. Repeat the analysis and see if there are any differences.
- ▼ Calculate the percentages of oxygen and carbon dioxide in the air samples you have tested.

Requirements

J-tube apparatus, using 5 cm³ syringe if possible
4 x 50 cm³ beakers
Disposable bendy-straw
Boiling tube
Bowl, large enough to hold the boiling tube held horizontally
Safety glasses
Disposable gloves
Ruler marked in millimetres

Concentrated potassium hydroxide solution
Concentrated pyrogallol (pyrogallol)
Dilute hydrochloric acid
Tap water

Safety Considerations

Concentrated potassium hydroxide (KOH) solution, pyrogallol, and dilute hydrochloric acid are corrosive, and should only be handled while wearing lab coats, gloves and eye protection.

Major spills should be wiped up immediately by the supervisor or technician, using plenty of water, and adding neutralising chemicals if they are available.

When the J-tube contents are expelled, either during or at the end of the exercise, they should be expelled into a sink, with the tap running to wash the chemicals away quickly.

Drips of any of the chemicals onto the bench should be wiped up immediately with a disposable towel.

Unit 2H:

Exchange, Transport and Reproduction in humans

2H.2 Transport of materials

The circulatory system

Practical work should include an investigation of the effects of physical activity on pulse rate.

An investigation of the effects of physical activity on pulse rate

Introduction

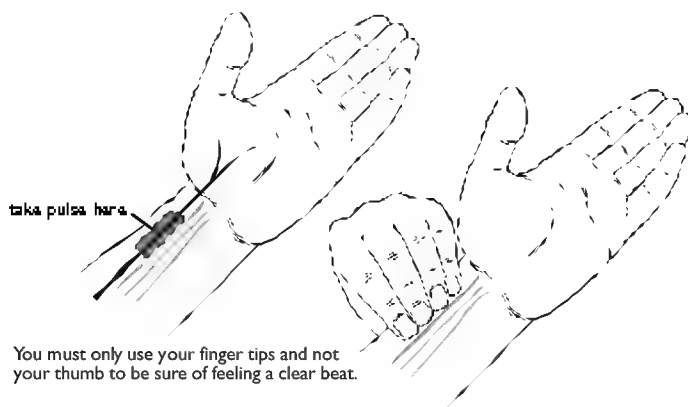
The heart rate increases during exercise to supply the muscles with extra blood containing oxygen and glucose, and remove carbon dioxide.

In this simple investigation the pulse rate will be measured.

How the pulse rate responds to exercise in different individuals can be investigated. Groups of three are best for this investigation: subject A to exercise, B to check the pulse, and C to time and record.

Method - Measuring the Resting Pulse Rate

The pulse can be felt in the radial artery at the wrist as shown.



- ▼ Allow the subject to settle for two minutes (whilst standing).
- ▼ During this time locate the pulse in the left arm as illustrated (do not use your thumb).
- ▼ After 2 minutes count the pulse beats for 30 s, and record the result in a suitable table.

continued

- ▼ It is possible to count for a shorter period e.g. 6 s, but when measuring the resting pulse rate the longer the counting time, the more accurate is the conversion to beats per minute (*bpm*)
- ▼ At the end of counting, leave the subject at rest for a further 2 minutes (whilst standing).
- ▼ Repeat the 30 second pulse count procedure, and record the results.
- ▼ Allow to rest for 2 minutes (whilst standing).
- ▼ Repeat the 30 second pulse count procedure, and record the results.
- ▼ Convert all results to pulse beats per minute and work out the average.

Sample Method - An investigation into the effect of exercise on the pulse rate

- ▼ Before you start exercising, make sure that all members of the group have submitted a prior consent form.
- ▼ Subject A then exercises at a steady rate for 3 minutes. This exercise can be using an exercise bike, or jogging on the spot, or stepping up and down using a box or the stairs. It is important that the exercise should be at a steady rate, which is one that the entire group can keep up with: it is probably a good idea if the least fit member of the group goes first.
- ▼ Immediately after the exercise, B should count subject A's radial pulse, while C keeps track of the time and records the results. Count the pulse rate for 30 s, then multiply the result by 2. Subject A should not try to count the pulse themselves, as this can influence the results.
- ▼ Continue to count pulse rate for 30 s of each minute for four minutes, while subject A rests (standing). Do not stop the clock between measurements, by counting for 30 s only you should have time to record the results for each minute before you start the next.
- ▼ Change roles within your group, and repeat the process (steps 2-4) for each student in your group, so you have all exercised, and recorded results etc.
- ▼ If you have time, repeat the whole process again for all members of your group, to check the reliability of your results.

In your report, present the data in suitable ways and consider the different results from members of your group, see if you can relate them to different levels of fitness. Evaluate your evidence and method.

Teaching Notes

Generally the resting pulse rate is taken when the subject is flat on their back. However, where the intention is to investigate the effect of exercise on the pulse rate, it may be better to measure the 'resting' pulse rate standing, otherwise there is an increase in the pulse rate associated with getting up to participate in the exercise.

To investigate the effects of exercise on the body it is necessary to establish a standard rate of exercise, during and immediately after which it is possible to record various measurements of the effect of exercise.

The validity and reliability, and relative safety of sub-maximal and maximal tests should be understood.

The ability to extrapolate from sub-maximal results to maximal results, and the correlation between various measures of body response to exercise, will all ensure a scientific approach to the investigation.

A cycle ergometer, heart rate monitor, and stethograph allow accurate and reliable recording, but are beyond the reach of many. For those without access to these, the Step Test, along with simple measuring of e.g. heart rates (pulse rates), breathing rates, temperature, and even composition of expired air (procedure attached) can still produce reasonably valid and reliable results.

Sub-maximal tests like the Step Test pose less risks for the subjects and the responsible supervisor than do maximal tests like the shuttle run, or those that can be performed on the cycle ergometer.

The step test involves stepping up and down a measured height at a controlled rhythm, requires the minimum of apparatus and space, and can be administered to large numbers at the same time. The stepping height can be adjusted for individuals, for example from between 10 cm and 50 cm, depending upon the height and weight of the subject. The stepping rhythm is established with the aid of a pre-recorded signal, of so many steps per minute (*22 for females and 24 for males*). There is always the risk of stumbling, so care must be taken.

The pulse rate can be taken before, during and after a standard stepping period (*usually 3 or 5 minutes*). Once the heart rate has returned to its pre-exercise resting rate, the work period can be repeated if necessary with increased effort, for example by increasing the mass with added weights, and/or the rate of stepping.

Step tests are theoretically as valid (*they should measure what they claim to measure*) and reliable (*they should do so consistently*) as cycle ergometer tests. However, they rely on doing work by raising the body weight against gravity at a set rate, and their validity and reliability depends on correct stepping technique which is difficult to maintain. Any change in the height due to poor leg extension, or in the rate of stepping during a test, will change the work rate, usually reducing it, and this will invalidate the results. Stepping efficiency is also affected by the length and proportions of the legs.

SYKES, K. (1987) *Fitech Step Test*. Fitech Ltd. Alan House, 17-19 Boughton Road, Chester, CH3 5AE.

Also see: HEYWARD, V. H. (1991) *Advanced Fitness Assessment and Exercise Prescription*. Human Kinetics Books, Champaign, Illinois.

continued

This can be a straightforward practical exercise, which can give some interesting results, with a minimum of apparatus needed; especially if the age, sex or level of fitness varies within each group. It is usually best if they work in groups of three: this provides 1 subject, 1 to count pulse rate, and 1 to check timing and record results.

You need to make sure students are checking the pulse rate properly, and that they have made the practical as valid and fair as possible, with equal levels of exercise, etc.

In recent years, electronic heart rate monitors (HRM's) have become more readily available. Clear advantages offered by HRM's over manual pulse-taking are that heart rate can be continuously measured over extended periods of time, and also during a wide range of physical activities which do not lend themselves to periodic bouts of wrist holding. The range of the transmitter is about 1metre; this is not a great distance but it does not usually create any practical problems. The receiver, depending on the model and the cost, may give a simple digital display of current heart rate, or it may be capable of storing heart rate data in a number of files which can be retrieved either manually or down-loaded to a PC.

Requirements per group of 3

Step boxes, bench, or safe stairs, or exercise bike
Stopclock

Safety Considerations

The subject should be in good health and no pressure must be exerted on the subject to take part in the test activity, neither should any element of competition be allowed to enter the proceedings.

It is advisable to ask the parents/guardians of your students to complete a prior consent form (or your students themselves if they are over 18) before asking them to be subjects for experiments: a sample copy is provided.

Sample Prior Informed Consent Form

Title of Investigation/Experiment:.....

Objectives:.....

Description of Procedure:.....

Questions: All questions relating to the investigation or experiment will be answered in full.

Safety: All the procedures to be used in this investigation/experiment are widely and commonly used in Schools and Colleges, and although all activity involves some risk of an accident, the risk of harm in this investigation/experiment is no greater than in normal everyday life, or than in a supervised practical lesson.

Right of Withdrawal: You are absolutely free to withdraw from the investigation/experiment at any time. If during the investigation/experiment you feel in any way uncomfortable and wish to stop, you should do so.

Reassurance of Confidentiality: All information obtained as a result of the investigation/experiment will be treated confidentially.

Availability of Results: The data may be recorded manually, and/or stored on a computer, but not in association with your name. You are entitled to a copy of your own results on request.

Use of Results: The data may be used in discussions and/or as part of assignments or projects, but not in association with your name. They will only be used to illustrate general physiological principles, and will not be used for diagnostic or any other purposes

Statement of Consent: I fully understand the nature of the tests, and agree to participate in this investigation/experiment. To the best of my knowledge I suffer from no illness or condition that will:

- i prevent me from successfully completing the tests,
- ii be made worse in anyway by my taking part in the tests.

Name of Subject:.....

Signed:.....

Date:.....

Name of Parent or Legally Authorised Representative:

.....

Signed:.....**Date:**.....

Unit 2H:

Exchange, Transport and Reproduction in humans

2H.2 Transport of materials

Blood and body fluids

Practical work should include the microscopic examination of stained blood films and the identification of cells.

The microscopic examination of stained blood films and the identification of cells

Introduction

Red blood cells are one of the smallest cells you will view under the light microscope, and although the smear is large enough, care still has to be taken to find the focus with the high power (x40) objective lens. The nuclei of white blood cells stain dark blue and when present in the smear are easily seen, however, they are few and far between and you may need to look at a number of fields of view to see examples of the different types of white cell. They are usually easier to spot using the medium power (x10) objective lens, you can then move to higher power to draw the cells.

Method

- ▼ You are provided with a prepared slide of a human blood smear. Examine it under the microscope using medium power (x10) objective lens, and then high power (x40) objective lens.
- ▼ Identify the various types of blood cell: red cells, granulocytes, lymphocytes, and monocytes.

Granulocytes	72%	(Lobed nucleus and granular cytoplasm)
Lymphocytes	24%	(Large circular nucleus fills most of the cell).
Monocytes	4%	(Larger cell with large kidney shaped nucleus).
- ▼ Draw examples of each type of cell, label them and annotate your drawings with details of their functions.
- ▼ Record the final magnification of your drawings (eyepiece × objective × size difference) near to the heading.
- ▼ Platelets are usually visible as clusters of small purple 'granules' in the plasma.

Teaching Notes

The nuclei of the leucocytes are stained purple; the cytoplasm is usually pale, with purple or pink-stained granules.

The different types of granulocyte, lymphocyte, and monocyte are found in the following proportions (as % total white cell count)

Granulocytes	72%	(70% neutrophils, 1.5% eosinophils, 0.5% basophils)
Lymphocytes	24%	
Monocytes	4%	

Measurement of the different blood cells would give a good opportunity to use the eyepiece graticule

Requirements per student

Microscope

Prepared slide of Human blood smear

Drawing materials

Reference books/photos etc.

Practical Work Sheet 'Measuring specimens under the microscope'

Safety Considerations

There are no safety considerations for this practical, other than the safe use of the microscope.

Unit 2H:

Exchange, transport and reproduction in humans

2H.4 Human reproduction and development

Reproduction

Practical work should include microscopic examination of the histology of ovary and testis.

Microscopic examination of the histology of ovary and testis

Introduction

The section of the testis should be clear, but remember, in cross section, the single coiled semeniferous tubule appears as a collection of apparently unconnected circles.

The section of the ovary represents a moment in time in the ovarian cycle. Each follicle develops and matures in one position in the ovary, and at any one time several follicles will be caught at various stages of development. A range of slides may have to be examined before all stages are seen. Remember that theoretical diagrams typically show all stage of development of the follicles around the ovary in sequence, even giving the impression that one follicle travels around the ovary during its development.

Keep these points on the interpretation of sections as seen under the microscope in mind, as you examine the slides.

Method

- ▼ Collect a prepared slide of a transverse section (T.S.) through the mammalian testis.
- ▼ Examine the slide under the microscope, first using the (x4 or x10) objective lenses, and identify the semeniferous tubules.
- ▼ Next examine a single semeniferous tubule under high power (x40) objective lens, and try to identify the spermatogonia, primary spermatocytes, spermatids, Sertoli cells and developing sperm. The nuclei of cells are clearly seen, but it is often difficult to make out cell boundaries.
- ▼ Using the medium power (x10) objective lens draw a plan of the seminiferous tubules, and using the high power (x40) objective lens make a detailed drawing of part of the wall of one tubule. Compare what you see with photographs and diagrams, and label and annotate your drawings.
- ▼ Now examine the prepared slide of the longitudinal section (L.S.) of the ovary, using the medium power (x10) objective lens. Identify any developing follicles that are visible. Make a simple low power drawing of what you see. Compare what you see with photographs and diagrams, and label and annotate your drawings.
- ▼ Make sure your drawings have suitable headings.

Teaching Notes

If the mammal from which the slides have been made is identified, try to find out about the pattern of oestrus shown by that animal, as this will prevent the students assuming that there is a monthly cycle in the ovary in question.

Requirements per student

Microscope
Prepared slides of T.S. testis
Prepared slides of L.S. mammalian ovary (often rabbit)
Drawing materials
Reference material

Safety Considerations

There are no safety considerations for this practical, other than the safe use of the microscope.

Unit 3:

Energy and the environment

3.3 Energy flow

Reproduction

Practical work to include the estimation of pyramids of number and of fresh biomass using simple techniques for the collection and determination of fresh biomass.

The estimation of pyramids of number and of fresh biomass using simple techniques for the collection and determination of fresh biomass

Introduction

Seasonal variation can have a profound effect on the flora and fauna of different areas, so advanced planning of this exercise is important.

Method

- ▼ Work in groups of 4 - 5 for this practical. Collect one large tray and four smaller ones, and weigh each one using a balance. Label the small trays 'Producers', 'Primary Consumers', 'Secondary Consumers', and 'Decomposers' and note down the mass of each tray. Also note the mass of the large tray.
- ▼ Identify an area of ground that you can dig up, you will need to ask the permission of the landowner, so it is easier to use part of the school/college grounds, or your own garden. A grassy area is simplest to work with: if it is unmown this is all the better.
- ▼ Mark a line across the blade of a spade, which is 15cms from the bottom edge of the blade, using a marker pen or some coloured sticky tape. Measure the width of the blade in centimetres, and note this down.
- ▼ Mark a square on the ground whose width is the width of your blade. Use string and tent pegs to mark the square out. Carefully water the surface of the soil inside the square with a solution of soapy water. Wait 15 minutes, and very carefully collect any earthworms which rise to the surface of the soil during this time. Count the earthworms, gently wash the soapy water off, and place them in your large tray in the shade.
- ▼ Push the blade of your spade into the ground vertically along one side of your square, until the tape / marked line reaches the ground surface. Repeat this on all four sides of the square.
- ▼ Carefully remove the block of the soil which has been cut, down to a depth of 15 cm, and place all the block in the large tray (with the earthworms). If any insects or other organisms fall off the block while you are transferring it, collect them using pooters and place them in the tray as well.
- ▼ Take the tray into the laboratory, and weigh the whole large tray and contents. Calculate the mass of the whole block of soil, together with its plant and animal contents.

continued

- ▼ Carefully collect any animals which are easily visible in the large tray using a pooter or forceps (or fingers). Try to identify each animal, and decide whether it is a primary or secondary consumer, or a decomposer. Use books to help you, and place each animal in the appropriate tray. If you find an animal that can fit into two categories, decide whether you think its main food supply comes from plants, animals or dead materials and detritus, and place it in the appropriate tray. A piece of perforated Clingfilm laid over each tray will stop your organisms escaping and/or drying out, but still allow oxygen to enter.
- ▼ Tease apart the block of soil, using forceps, spatulas, sticks or whatever else is most useful. Remove any animals you find using the pooter or forceps, identify them and place them in the primary consumer, secondary consumer or decomposer tray as appropriate. Collect the plant materials, leaving the roots intact if possible, and place them in the Producers tray. Leave the remaining soil materials in the large tray.
- ▼ Using a 100g sample of the soil for each, set up a Tullgren funnel and a Baerman funnel. Collect the animals from the Tullgren funnel in a conical flask covered in dark paper or fabric, rather than in methanol, so they can be returned to the collection site afterwards. Leave the funnels for several hours if possible, but collect the organisms regularly, so that the carnivores do not eat the herbivores! Separate the animals into primary and secondary consumers as before, and add them to the relevant tray.
- ▼ Make a list of the species of organisms you have been able to identify.
- ▼ Once you have separated all the animal and plant materials from the block of soil, check each tray, to make sure that you have correctly separated the organisms. Count the number of organisms in each tray. Weigh each tray, and calculate the mass of organisms found for each trophic level.
- ▼ Collect a 50 cm³ beaker-full of the soil from the large tray, and tip it into a large measuring cylinder. Add water up to the top of the scale on the measuring cylinder. Put your hand over the end of the cylinder and shake it thoroughly. Top the water up to the top of the scale again if necessary. Leave the cylinder and contents on one side to settle out.
- ▼ Once the soil in the measuring cylinder has settled, measure the amounts of sand and clay particles in your soil using the volumes on the measuring cylinder, and the floating humus, and try to identify the type of soil: is it sandy, clayey, or loam? Measure its pH by placing a few drops of the water from the cylinder on a piece of indicator paper.
- ▼ When you have finished your investigation, take the trays back out to your collection site, and return the soil and animals to the hole where you collected them. If there is not too much plant material, plant it back in the hole as you replace the soil.
- ▼ Calculate the pyramids of number and fresh biomass for your block of soil. Also calculate the pyramids for a 1 metre square area, to a depth of 15 cm.
- ▼ If time permits, keep a watch over your collection site, to see how long it takes for your site to regenerate.

Teaching Notes

This is quite a long exercise, but should prove interesting. If you do not have a lot of time, it may be easier to collect only one block, and involve the whole group in the analysis and classification work. Inevitably it will only produce an estimate, but this is in the nature of all ecology work, which is a useful point to get across.

The collection of the earthworms may actually bring up more worms than are in the block, as the soapy water may penetrate below the 15 cm depth. However, by carrying this out first, you will reduce the chances of any earthworm being damaged by the spade when the block is cut.

The separation of the primary and secondary consumers is not always straightforward: the students may need some help with this. Examination of the mouthparts using a hand lens or microscope may help, as will some identification guides to soil organisms.

There is quite a lot of scope for extension or development of this practical, depending on the time available, and the interest of your students. They could observe the area beforehand to note down any birds or larger animals that feed in the area. More able students might like to put together a food web for the site. If you have the facilities, they could compare sites with different abiotic factors, such as shade, aspect etc.

The regeneration of the site could be followed and recorded after the soil has been replaced.

It is suggested that sites be identified which will not interfere with other school or college activities, and the area marked clearly.

Requirements per group of students

- One large tray and four smaller ones
- Marker pen
- Several pooters
- Several pairs of forceps
- Clingfilm
- Spade
- String, and 4 tent pegs
- Coloured tape (to mark the spade depth)
- Small watering can, or a large beaker (500 cm³ or more)
- Soapy water
- Balance, preferably an electronic one
- Tullgren funnel
- Baerman funnel
- 50 cm³ beaker
- 100 cm³ measuring cylinder (or larger)
- pH indicator paper or soil testing kit
- Identification books for soil organisms and possibly grassland plants.

Safety Considerations

Care must be taken in using the spade, and in control of general behaviour on open sites. The soapy water will not harm the soil: in fact, the phosphates it contains will act as fertiliser.

Biology or Biology (Human)



Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

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Contents List

Unit 1

Molecules and Cells

- 1 Monosaccharides and disaccharides
- 2 Polysaccharides
- 3 Structure of triglyceride
- 4 Phospholipids and the bilayer
- 5 Amino acid and peptide bond
- 6 Secondary and tertiary structures of proteins
- 7 Structure of haemoglobin
- 8 DNA and semi-conservative replication
- 9 Transcription
- 10 Translation
- 11 Table of codons for amino acids
- 12 Base sequence - gene code
- 13 Effects of temperature, pH, enzyme and substrate concentration on enzyme activity
- 14 Activation energy
- 15 Enzyme-substrate complex
- 16 Immobilised enzymes
- 17 Structure of bacterium
- 18 Magnification and resolution
- 19 Leaf structure
- 20 Root tip squash
- 21 Normal human karyotype A
- 22 Human karyotype analysed into homologous pairs (male)
- 23 Normal human karyotype B
- 24 Human karyotype analysed into homologous pairs (female)

Unit 2B

Exchange, transport and reproduction

- 25 Cubes 2 cm and 1 cm sides
- 26 Leaf structure (as 19)
- 27 Alveoli and associated capillaries
- 28 Human gut
- 29 Summary of structure of vessels in xylem
- 30 Summary of structure of sieve tube elements and companion cells in phloem
- 31 Ringing experiment (note that this is not an autoradiograph)
- 32 Mammalian heart
- 33 Closed double circulation
- 34 Simplified heart structure
- 35 Graph/chart of the cardiac cycle
- 36 Heart and SA node
- 37 Blood components
- 38 Bohr effect
- 39 Fetal and adult haemoglobin association / dissociation curves
- 40 Relationship between blood and lymph
- 41 Aerenchyma (T.S Water Lily)
- 42 Mosquito larva
- 43 Carpel with pollen tube developing
- 44 Plant ovule detail
- 45 Wind and Insect pollinated flowers
- 46 Menstrual cycle
- 47 Structure of reproductive organs - male
- 48 Structure of reproductive organs - female

Unit 2H

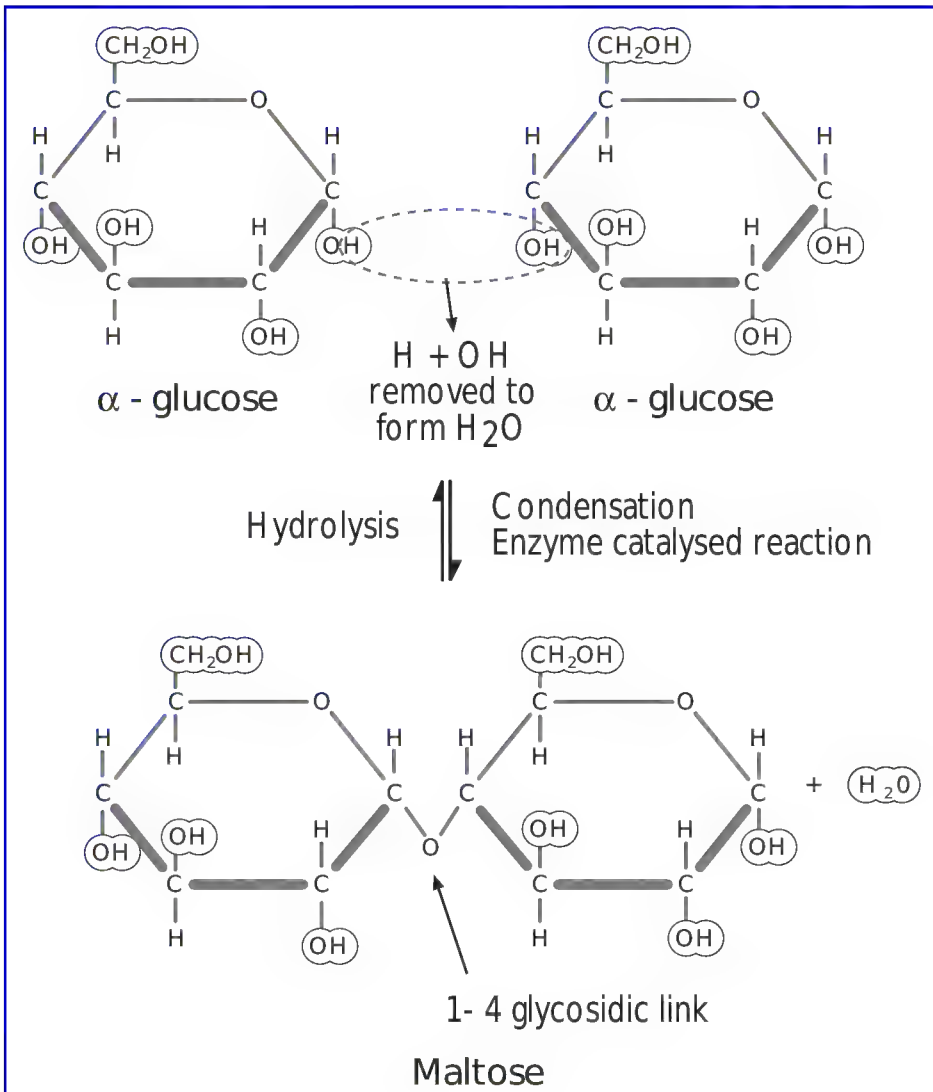
Exchange, transport and reproduction in humans

- 49 Spirometer traces
- 50 Simple apparatus for measuring carbon dioxide in expired air
- 51 Alveoli and associated capillaries (as 27)
- 52 Human gut (as 28)
- 53 Mammalian heart (as 32)
- 54 Closed double circulation (as 33)
- 55 Simplified heart structure association (as 34)
- 56 Diagram of heart and S node (as 36)
- 57 Graph / chart of the cardiac cycle (as 35)
- 58 Blood components (as 37)
- 59 Bohr effect
- 60 Fetal and adult haemoglobin association / dissociation curves (as 40)
- 61 Relationship between blood and lymph (as 41)
- 62 Structure of reproductive organs - female
- 63 Structure of reproductive organs - male
- 64 L.S Mammalian Ovary
- 65 T.S. Mammalian Testis
- 66 Menstrual cycle
- 67 Growth curves

AS Unit 3

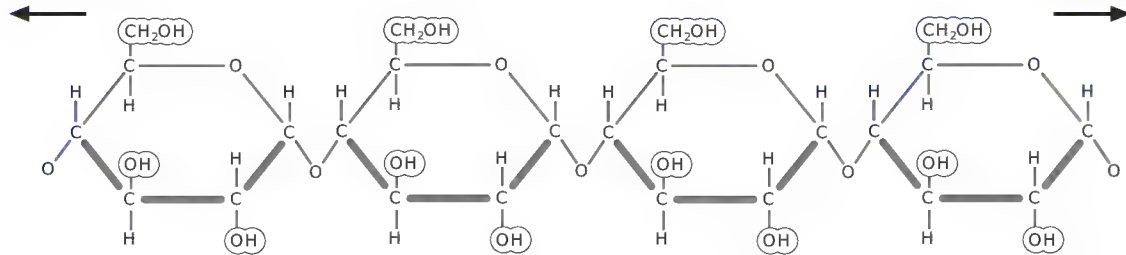
Energy and the environment

- 68 Sheep and dog skulls
- 69 Pyramid of energy
- 70 Pyramid of biomass
- 71 Nitrogen cycle
- 72 Depletion of oxygen in water



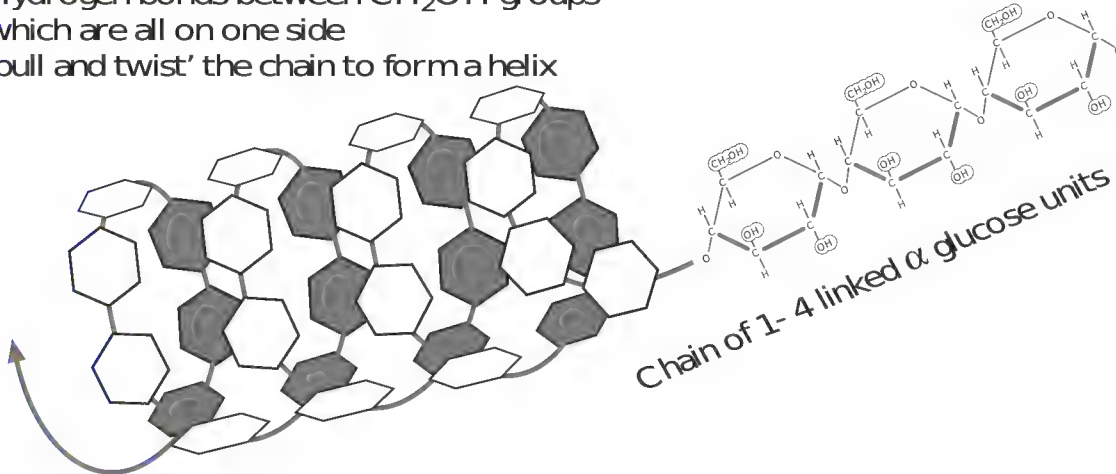
Part of amylose molecule chain

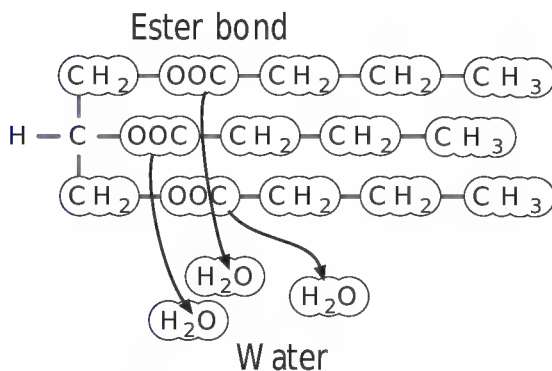
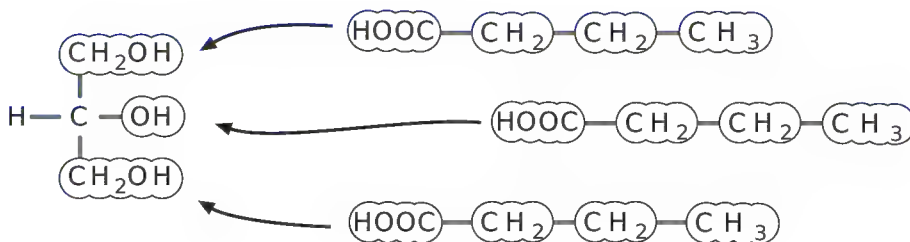
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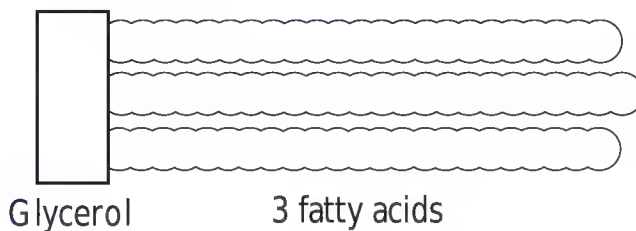
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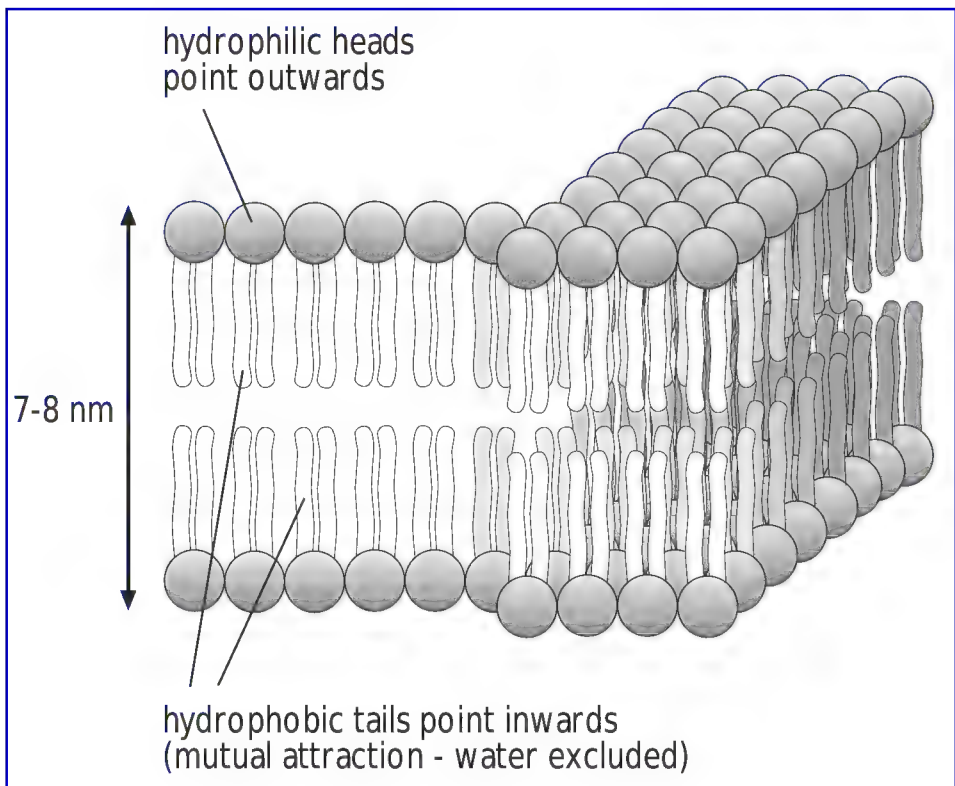
Hydrogen bonds between CH_2OH groups
which are all on one side
'pull and twist' the chain to form a helix

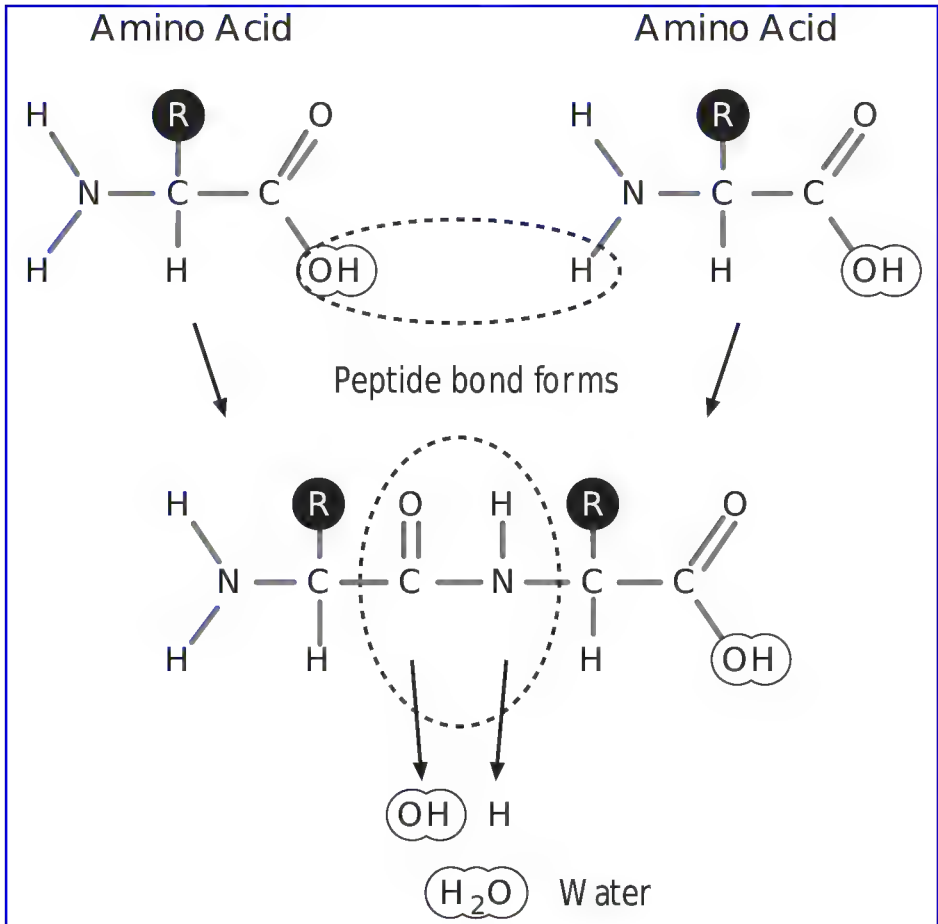




Model of a triglyceride

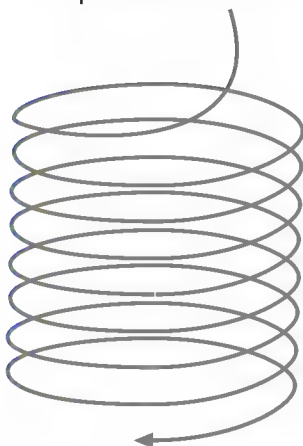




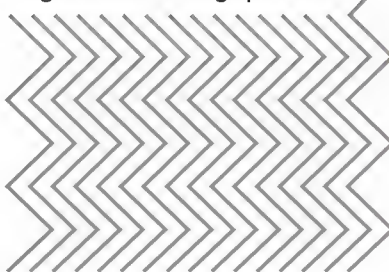


Secondary structure of proteins

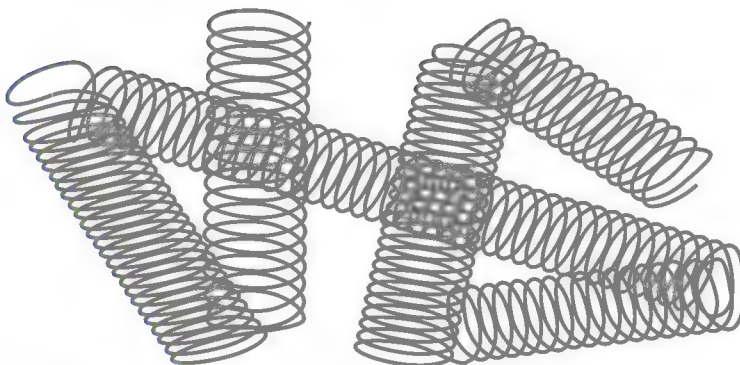
In an alpha helix hydrogen bonds 'pull' molecule chain into a spiral structure



In a beta sheet hydrogen bonds hold and align molecule chains side by side. Angle of bonds in each chain are as a consequence perfectly aligned forming 'pleats'.



Tertiary structure of proteins



The alpha helix chain folds around itself forming a third level of structural organisation, just like a tangled telephone flex

Primary structure

Amino acids join to form a polypeptide chain

side chains

helix held together by hydrogen bonds

Tertiary structure

Helix folds to form compact globular unit around Haem group

haem group

Secondary structure

Polypeptide chain folds in upon itself to form a helix

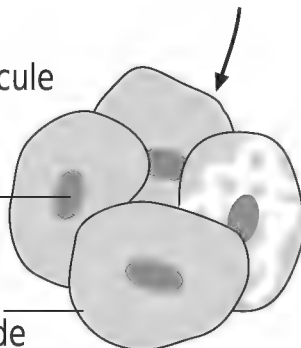
Haemoglobin molecule has four subunits

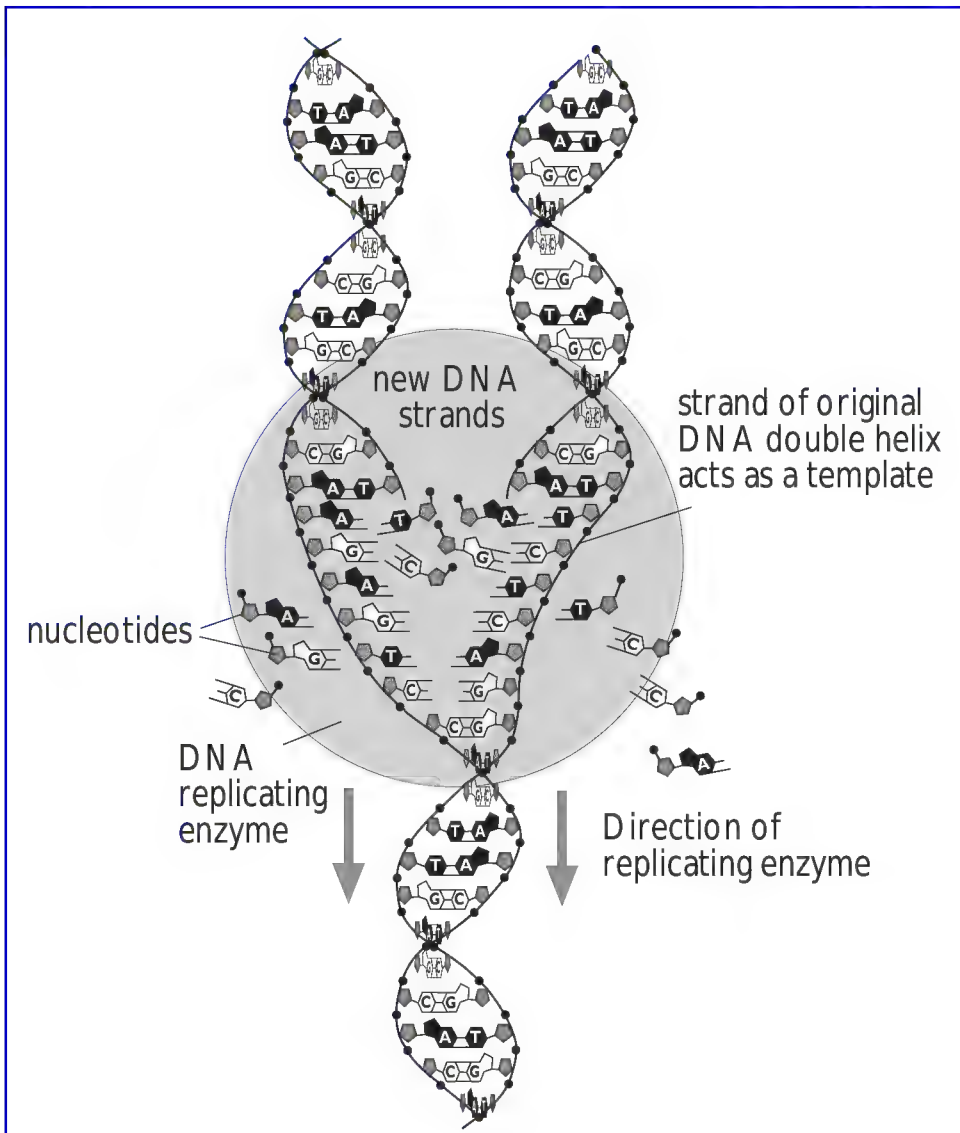
Quaternary structure

Several polypeptide chain units come together held by disulphide bridges to form a functional protein

haem group

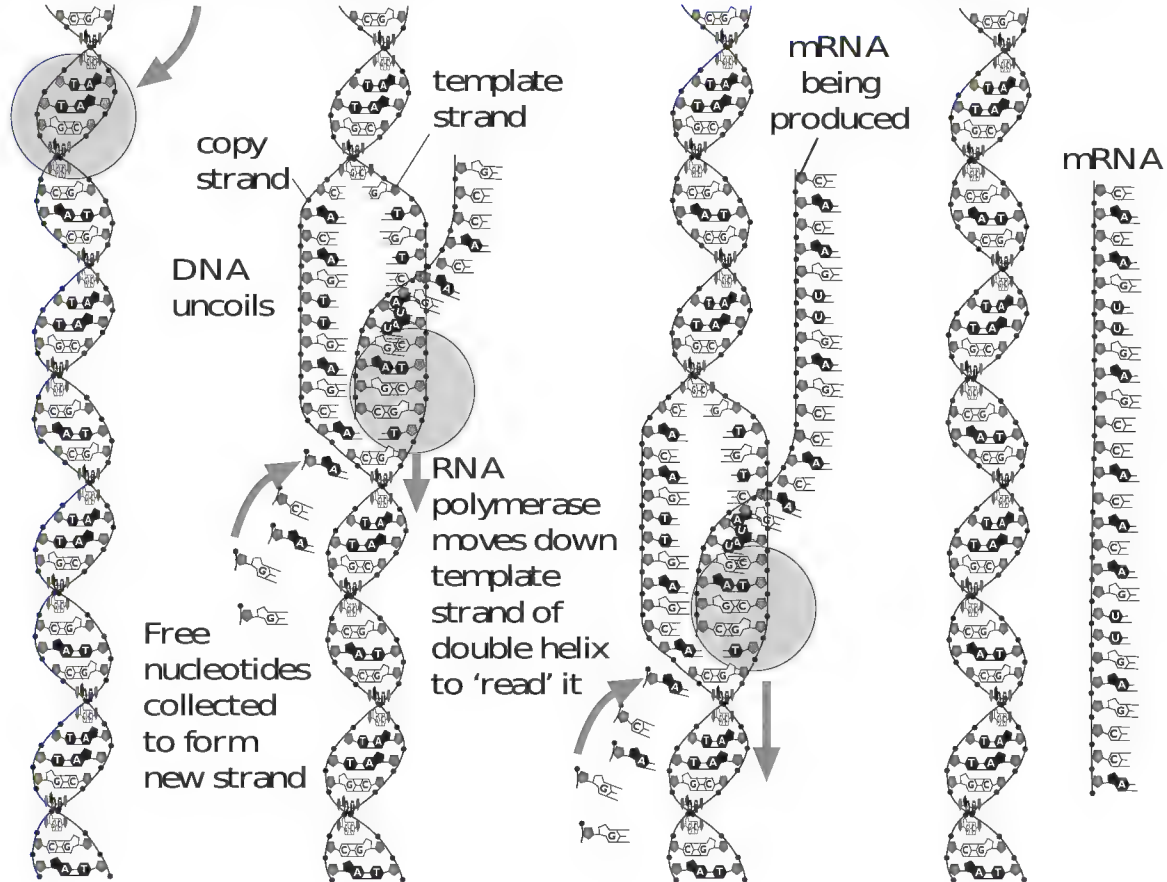
globular polypeptide subunit



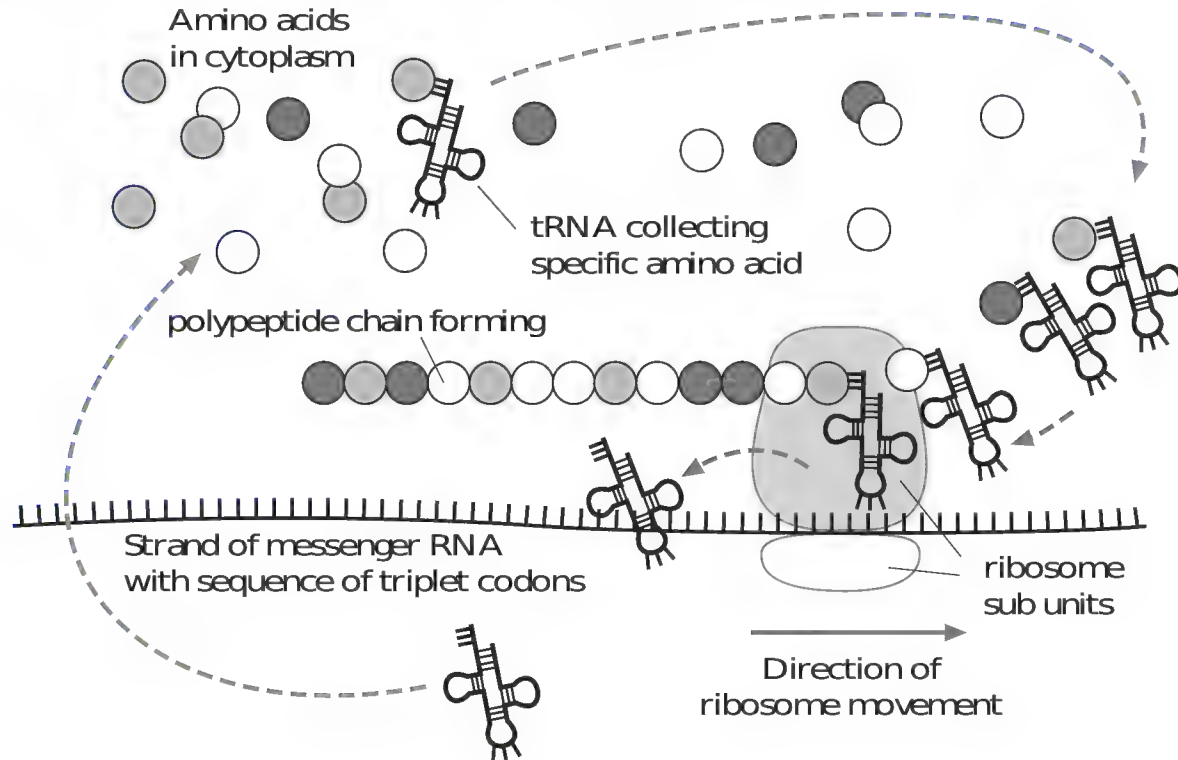


RNA polymerase attaches to DNA strand at specific codon site

DNA double helix rewinds to original

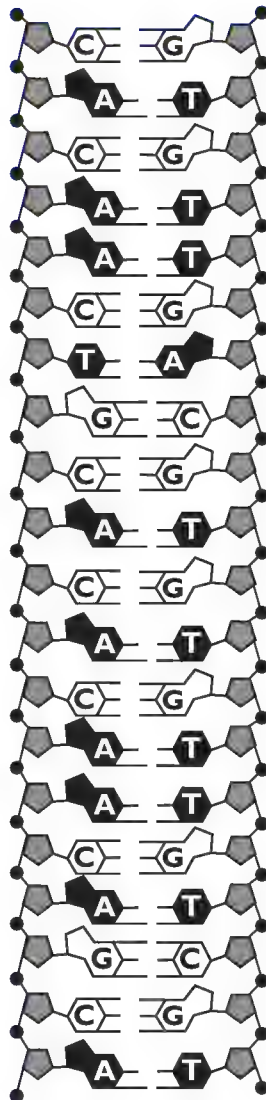
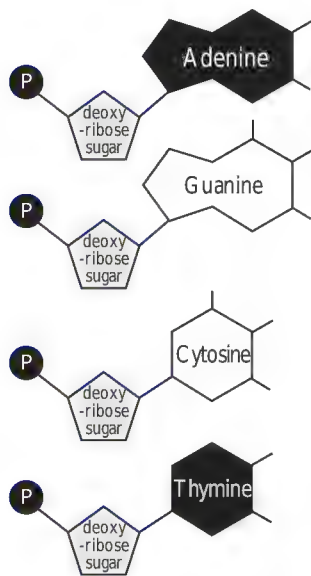


Translation of mRNA code to build a polypeptide

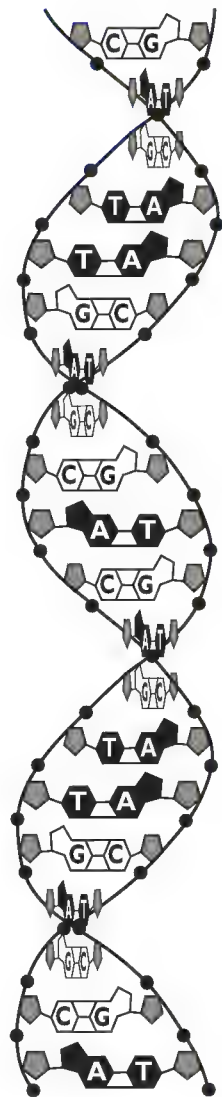


Amino acid	Abbr.	mRNA codons	Essential
Alanine	Ala	GCA, GCC, GCG, GCU	
Arginine	Arg	AGA, AGG, CGA, CGC, CGG, CGU	infants only
Asparagine	Asn	AAC, AAU	
Aspartic acid	Asp	GAC, GAU	
Cysteine	Cys	UGC, UGU	
Glutamic acid	Glu	GAA, GAG	
Glutamine	Gln	CAA, CAG	
Glycine	Gly	GGA, GGC, GGG, GGU	
Histidine	His	CAC, CAU	infants only
Isoleucine	Ile	AUA, AUC, AUU	E
Leucine	Leu	CUA, CUC, CUG, CUU, UUA, UUG	E
Lysine	Lys	AAA, AAG	E
Methionine	Met	AUG (Start codon)	E
Phenylalanine	Phe	UUC, UUU	E
Proline	Pro	CCA, CCC, CCG, CCU	
Serine	Ser	AGC, AGU, UCA, UCC, UCG, UCU	
Threonine	Thr	ACA, ACC, ACG, ACU	E
Tryptophan	Trp	UGG	E
Tyrosine	Tyr	UAC, UAU	
Valine	Val	GUA, GUC, GUG, GUU	E
STOP CODONS		UAA, UAG, UGA	

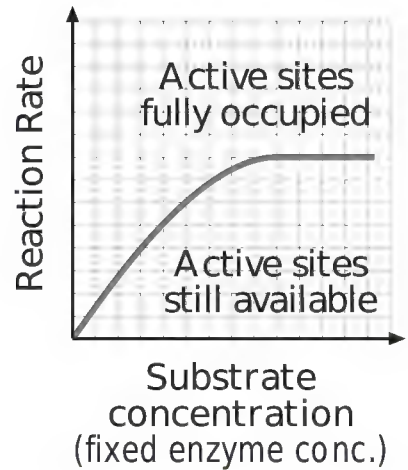
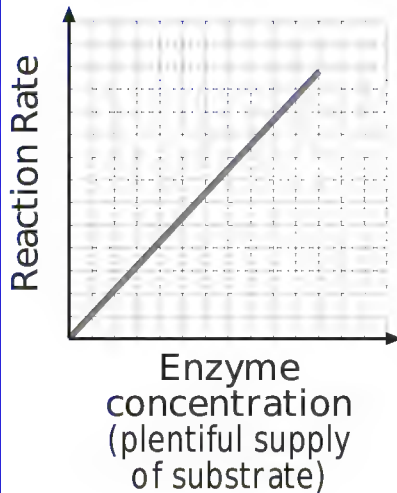
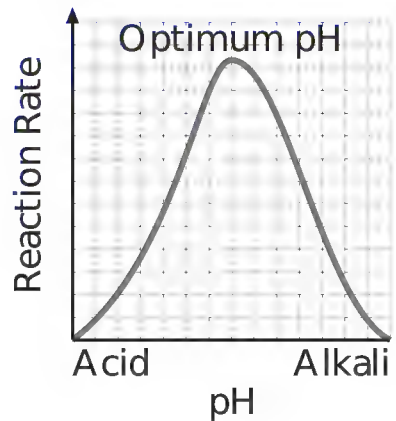
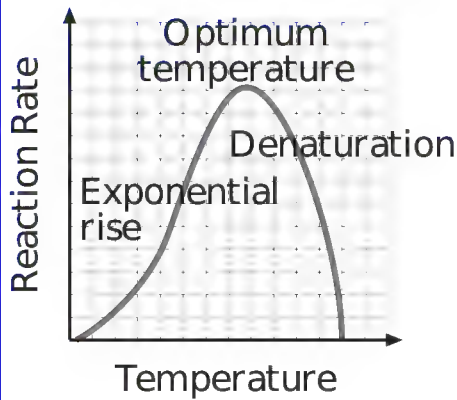
The Nucleotides of DNA

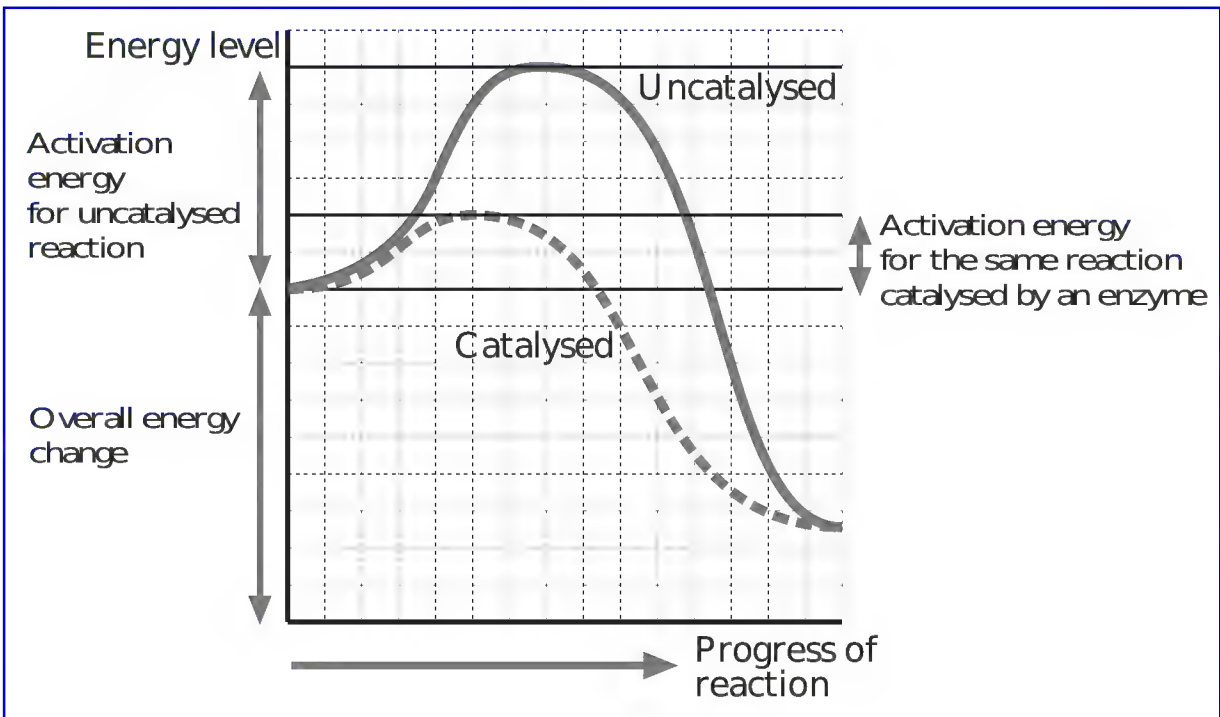


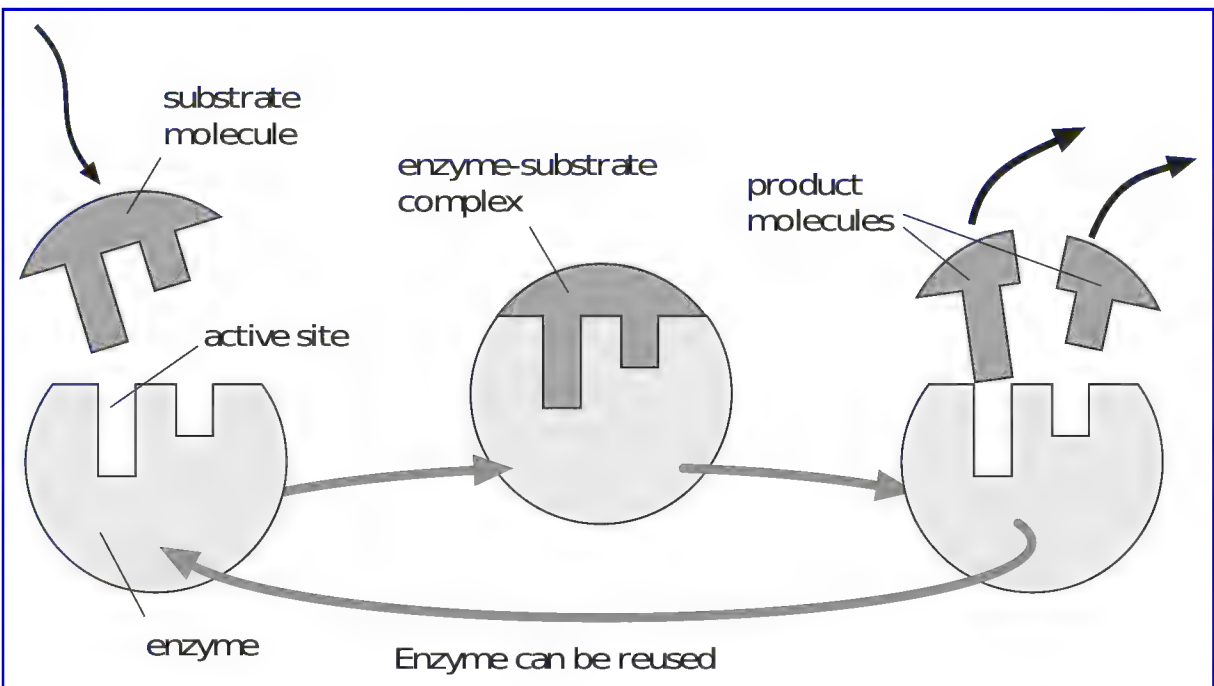
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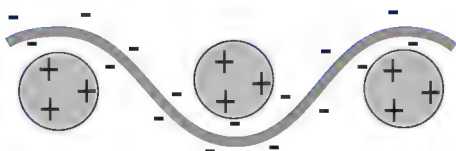
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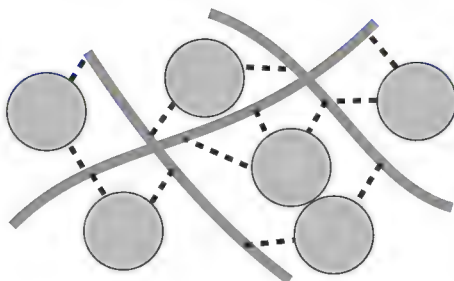




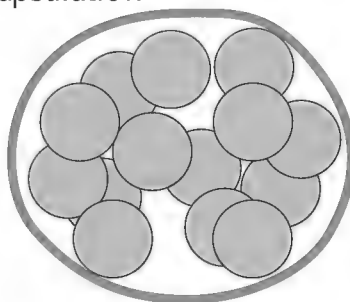
Absorption



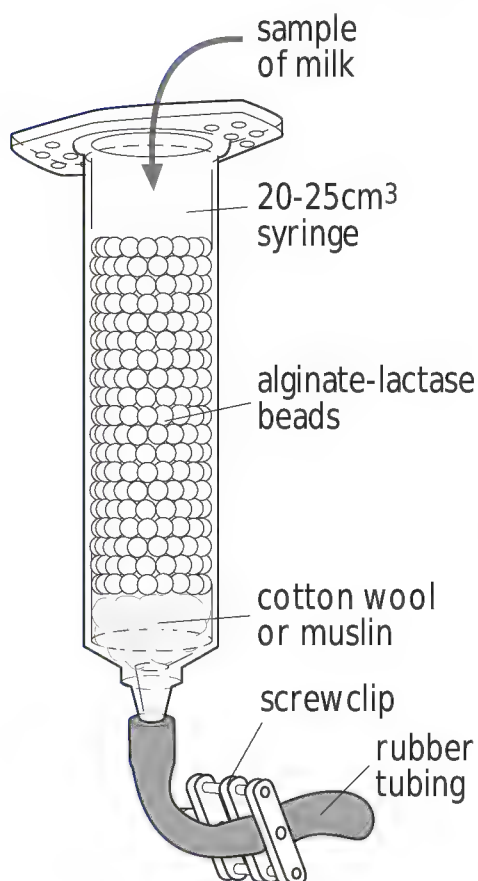
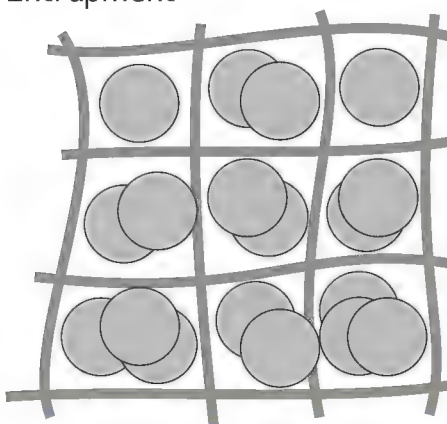
Covalent binding

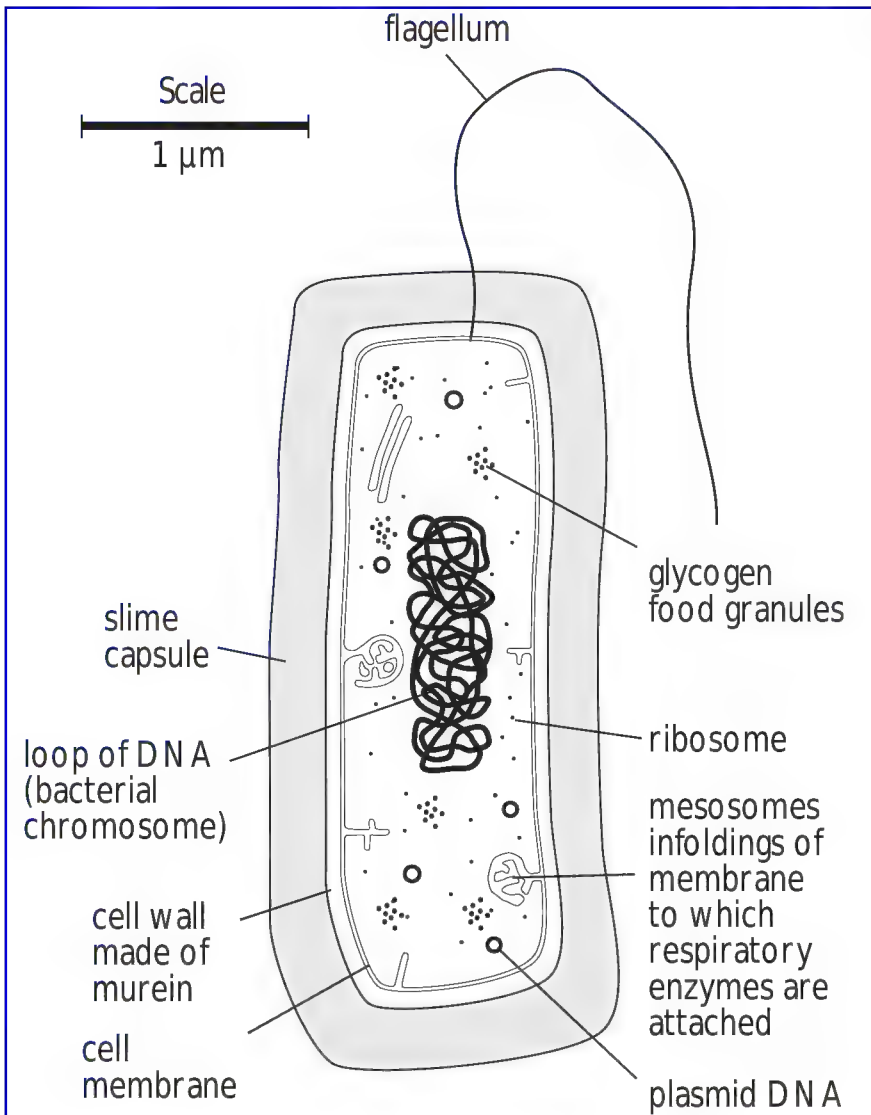


Encapsulation



Entrapment



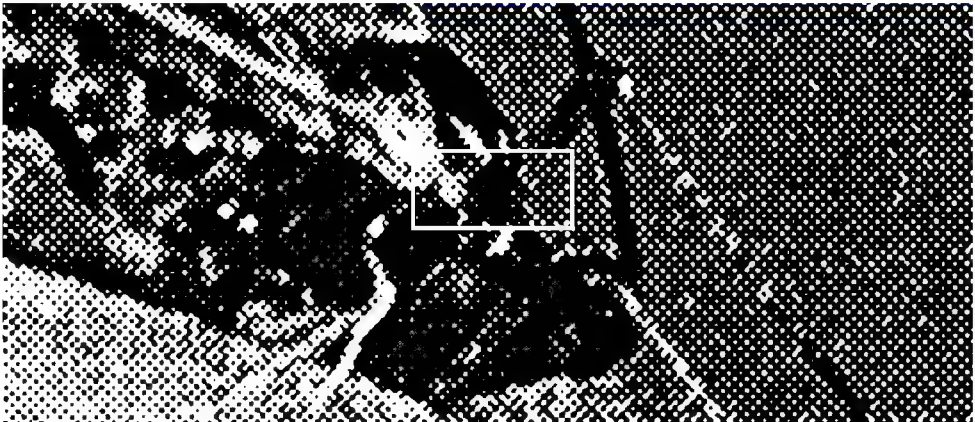
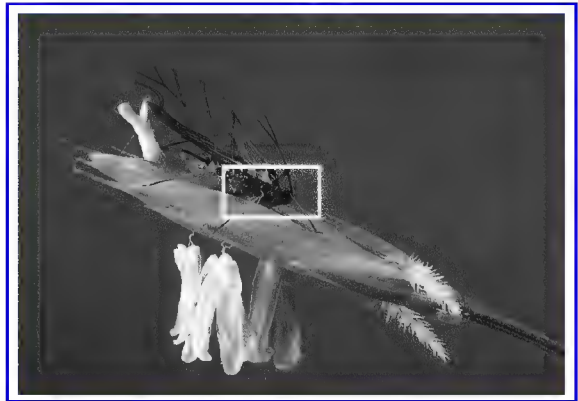


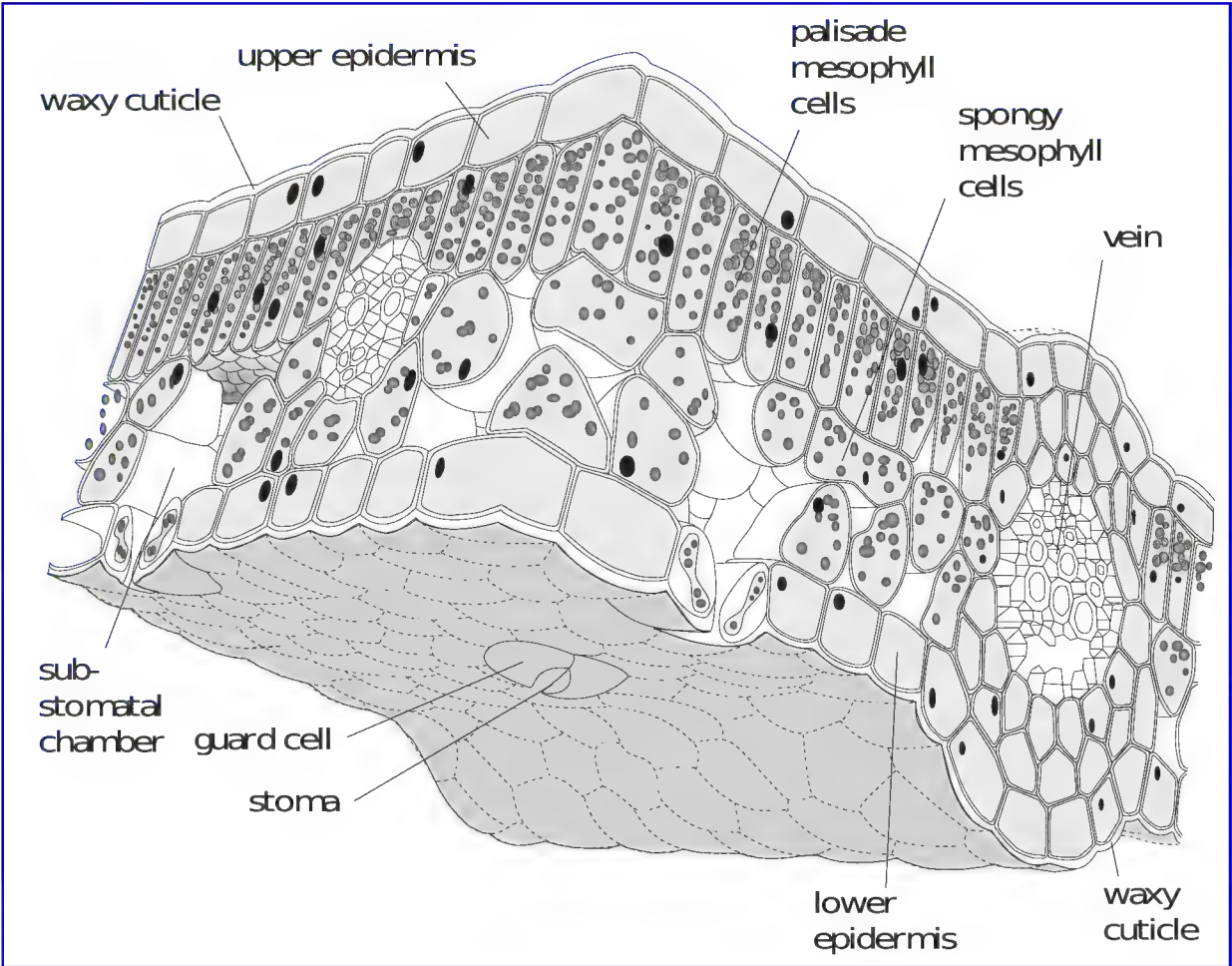
The image is composed of dots.

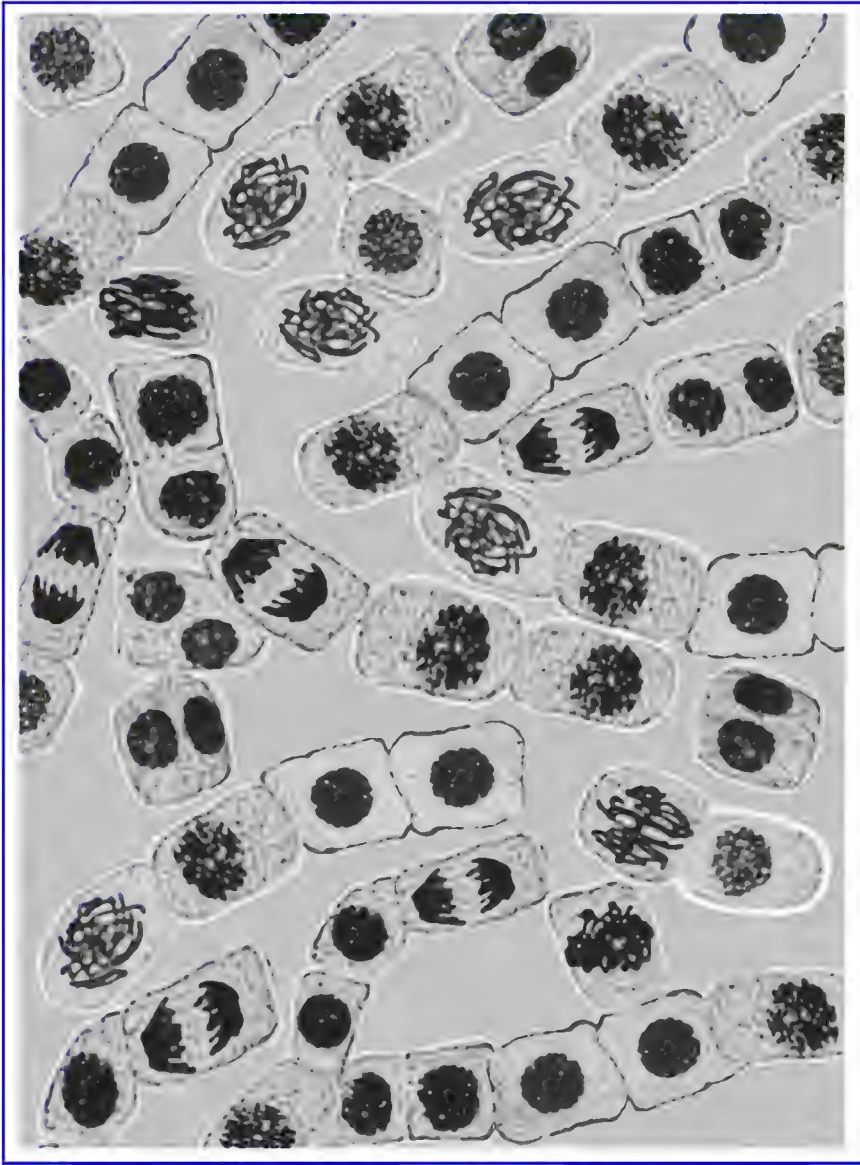
No amount of **magnification** will reveal any more detail or information ie; nothing more can be **resolved**.

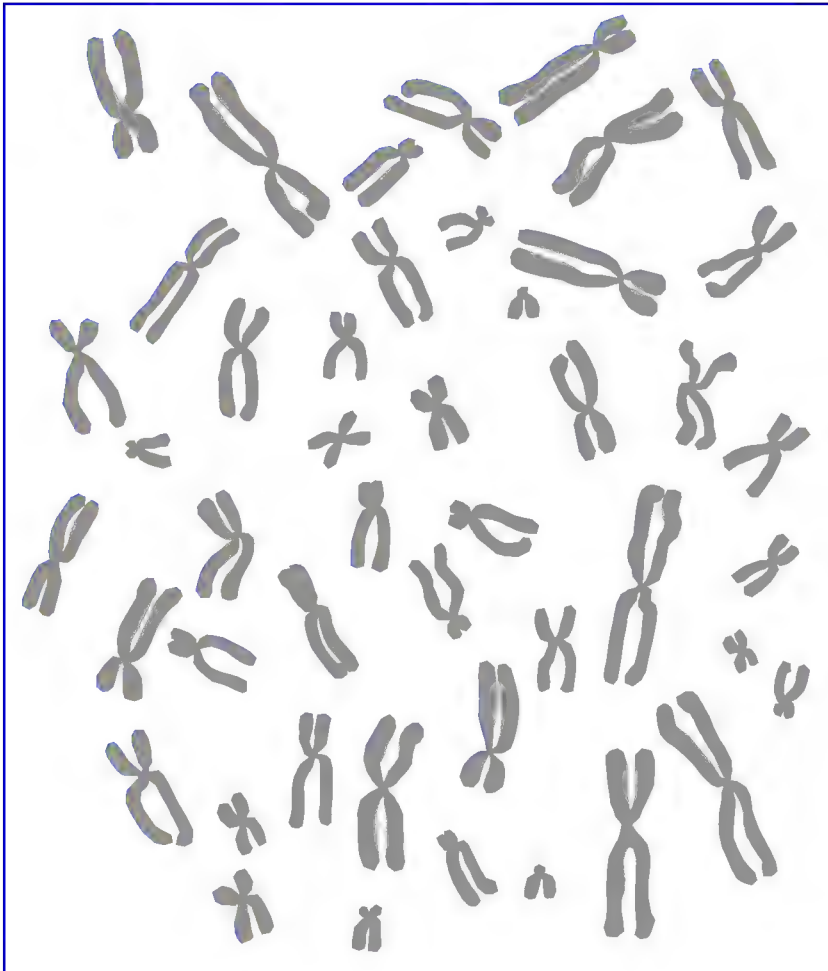
Magnification increases the apparent size of an object.

Resolution is the ability of an optical system to distinguish between adjacent points.

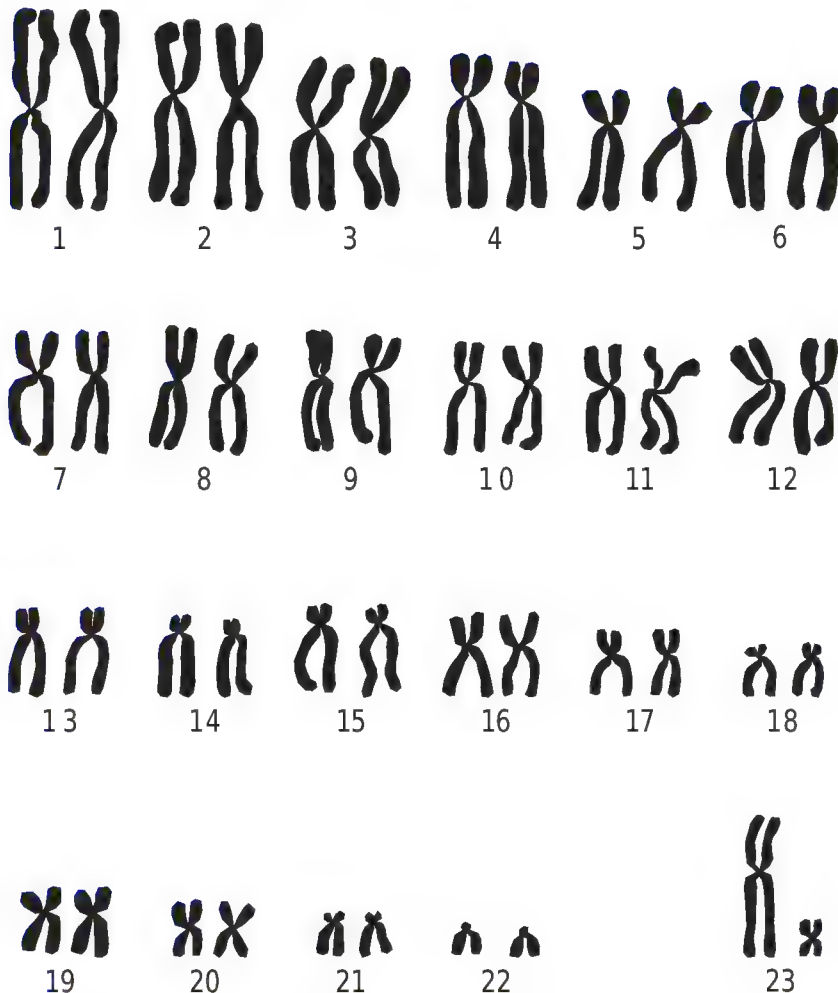


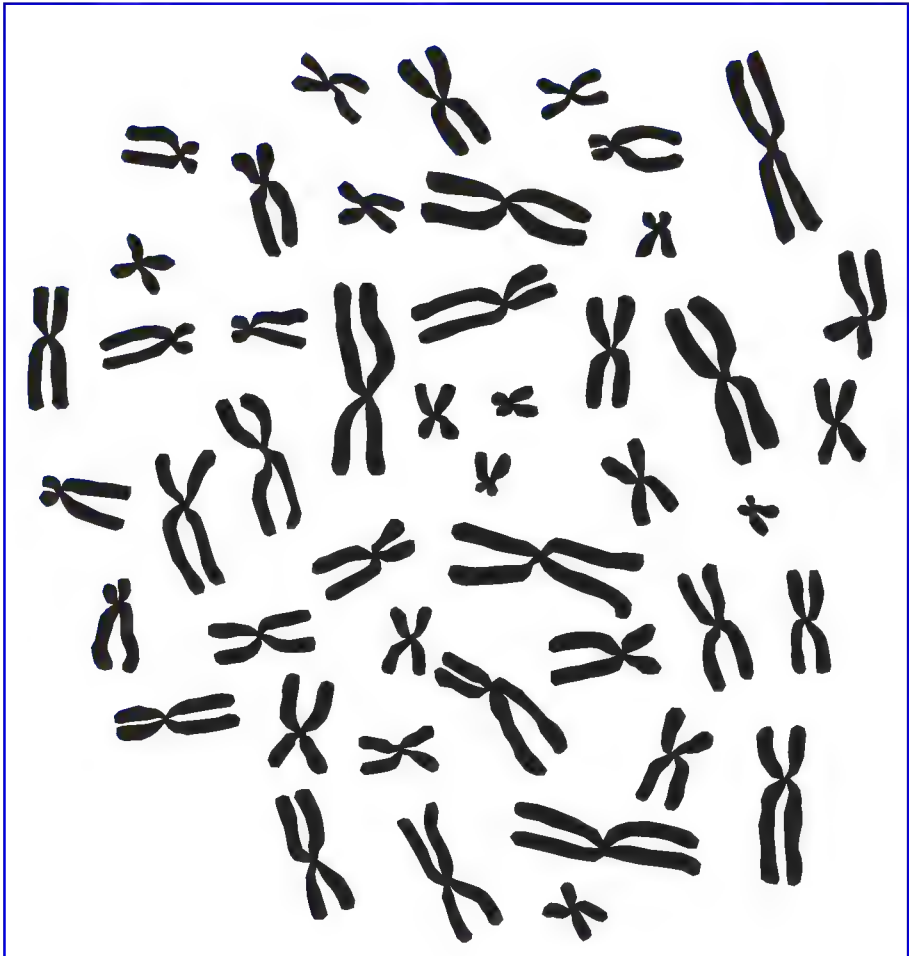






Normal Human Male

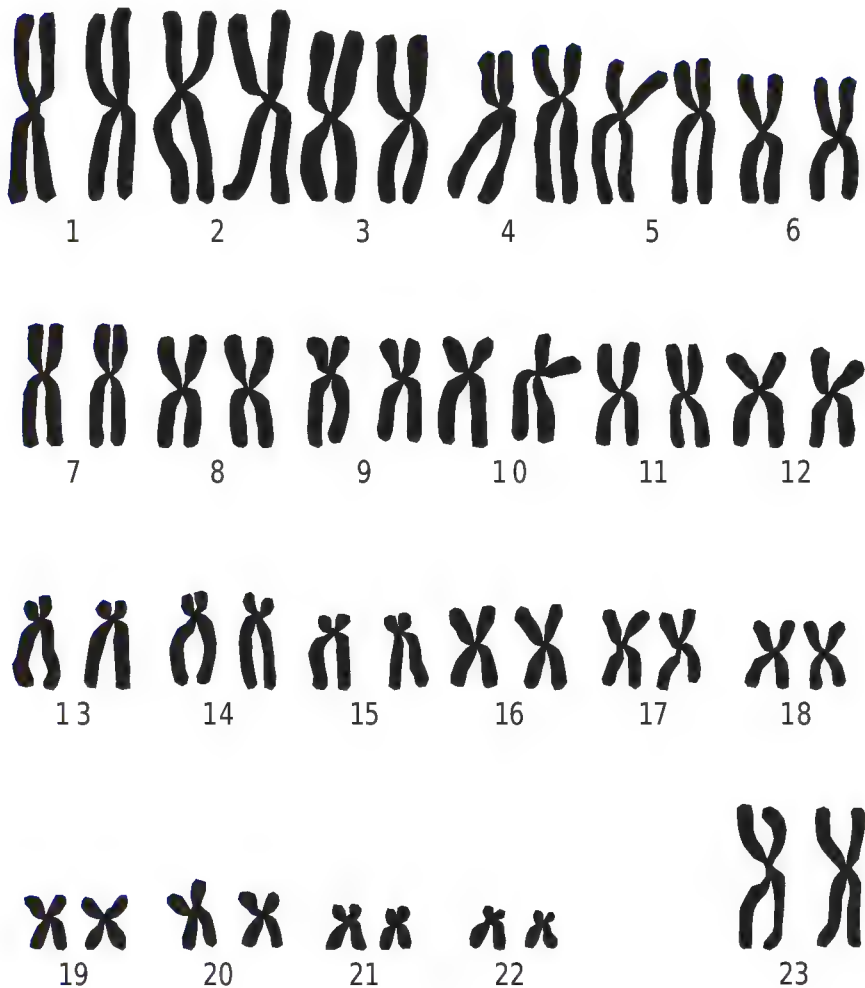




Normal human karyotype
analysed into homologous pairs

OHT Master 14

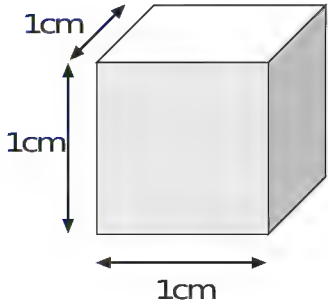
Normal Human Female



Surface area = 6cm^2

Volume = 1cm^3

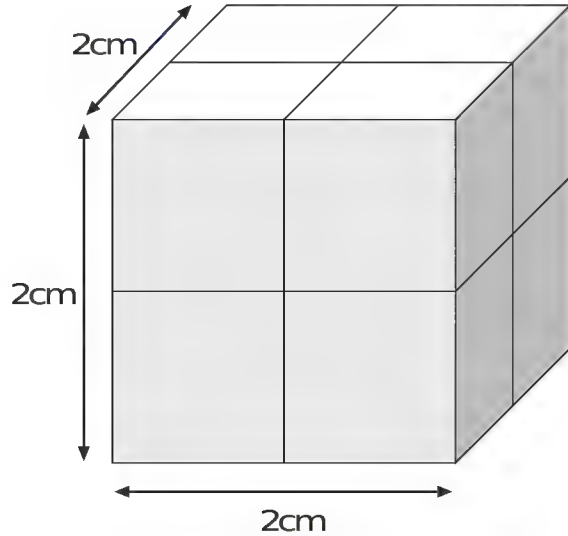
Surface area to volume = $6:1 = 6$

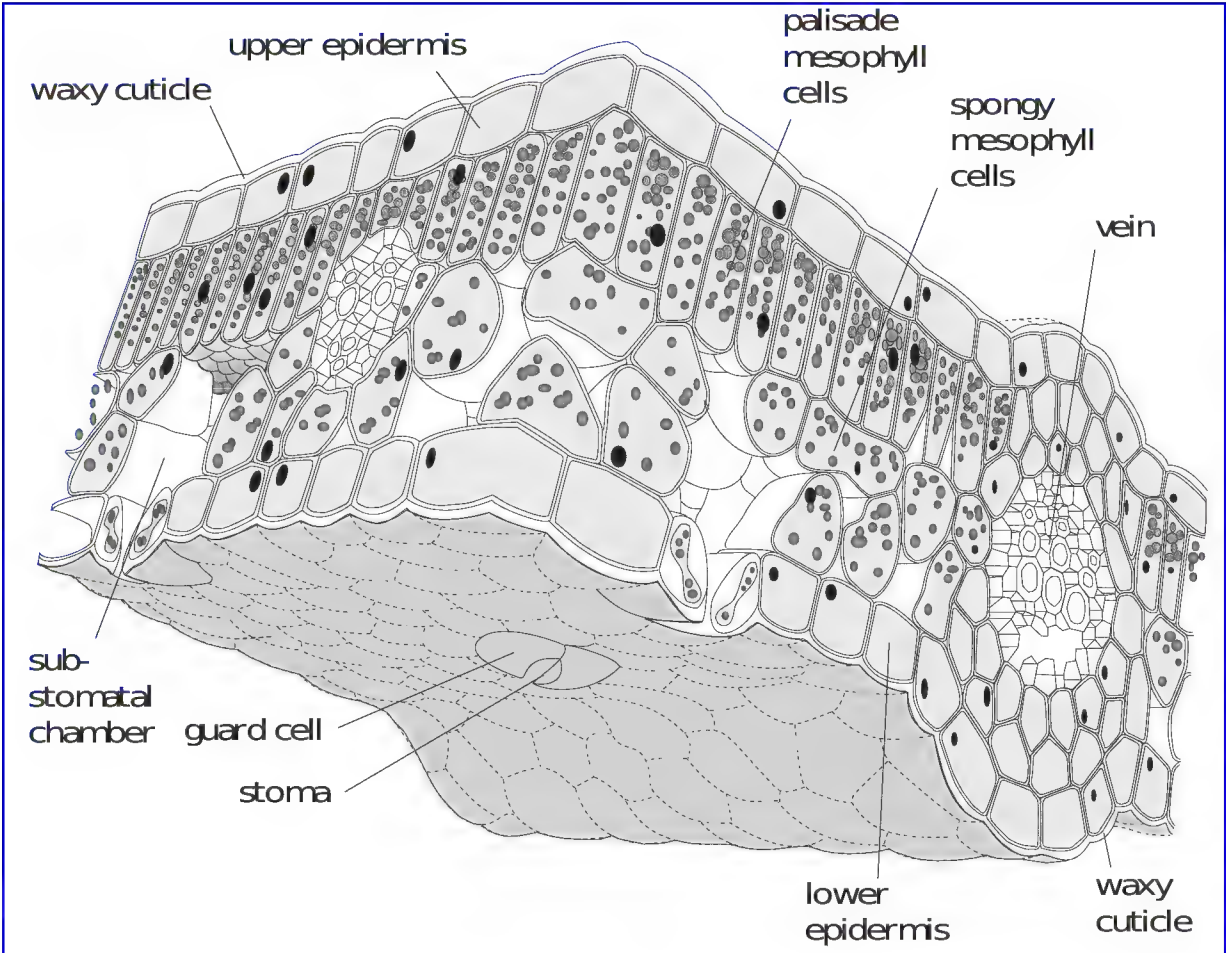


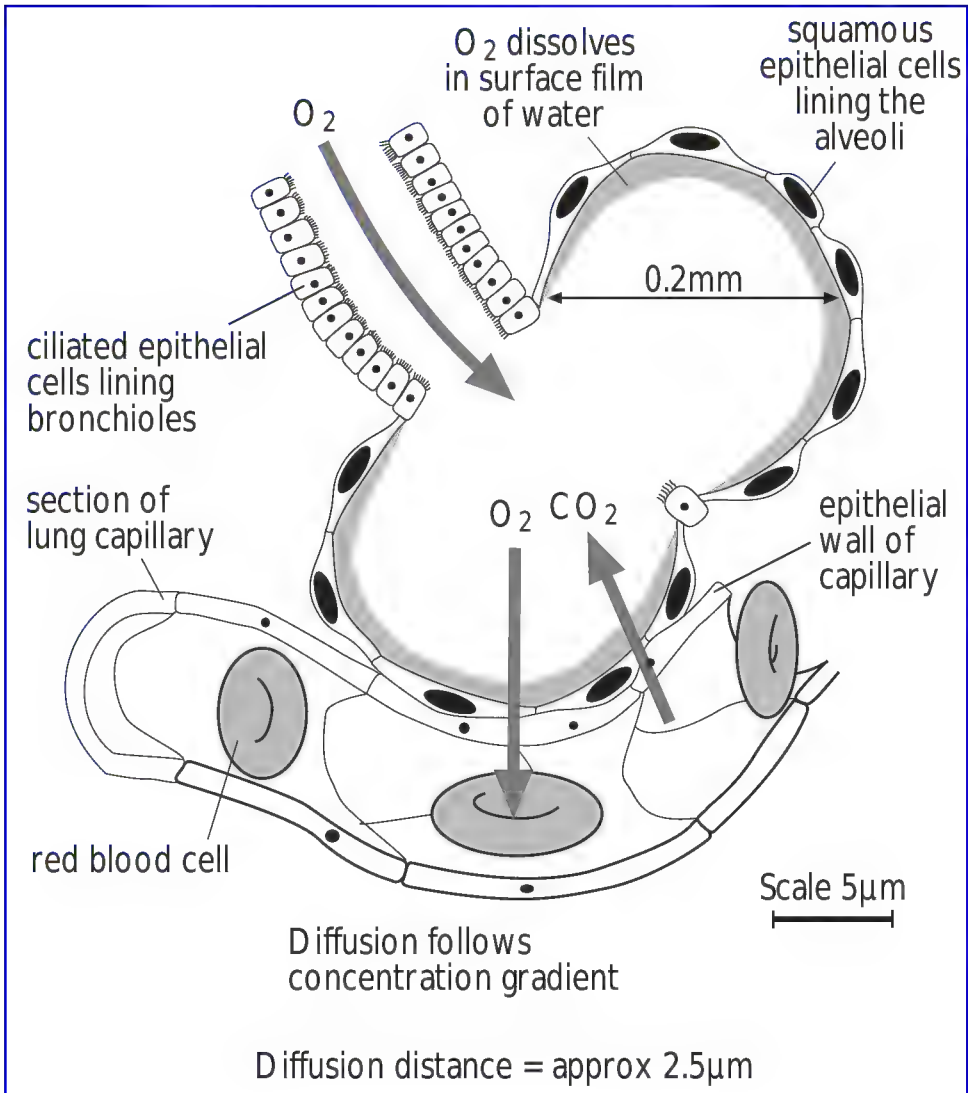
Surface area = 24cm^2

Volume = 8cm^3

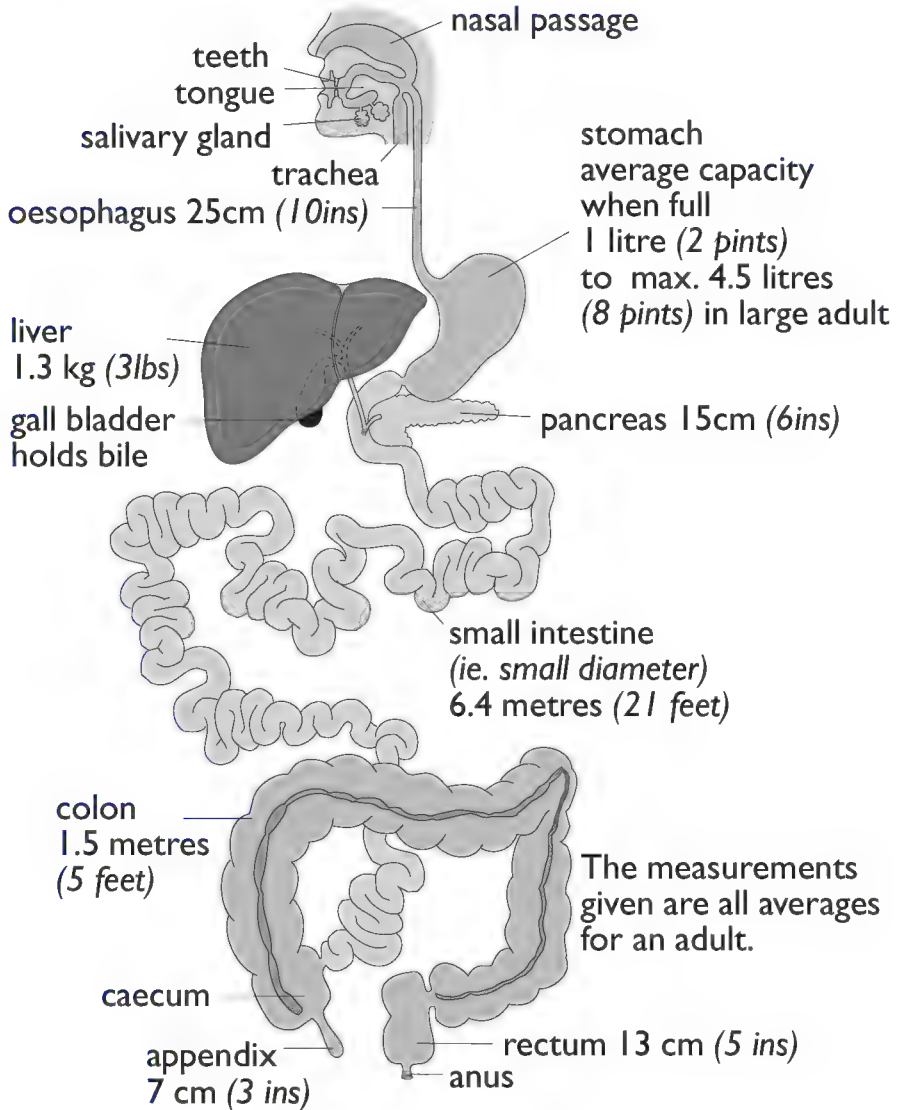
Surface area to volume = $24:8 = 3$



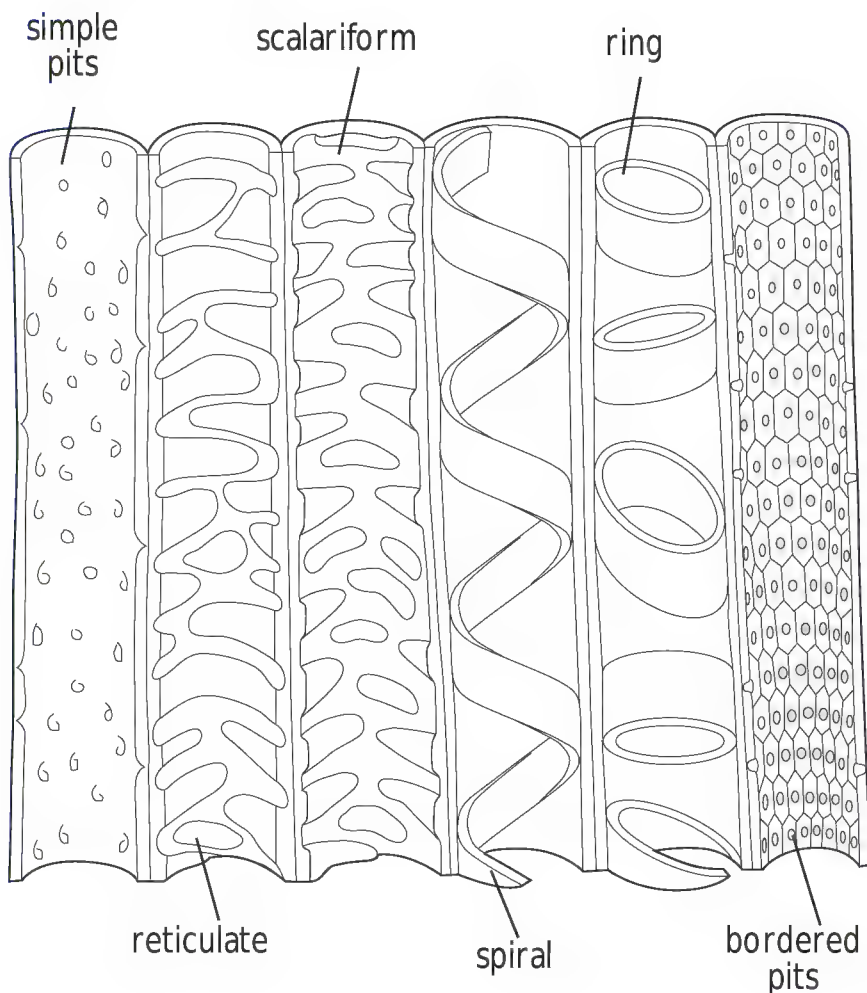




Digestive System Displaced

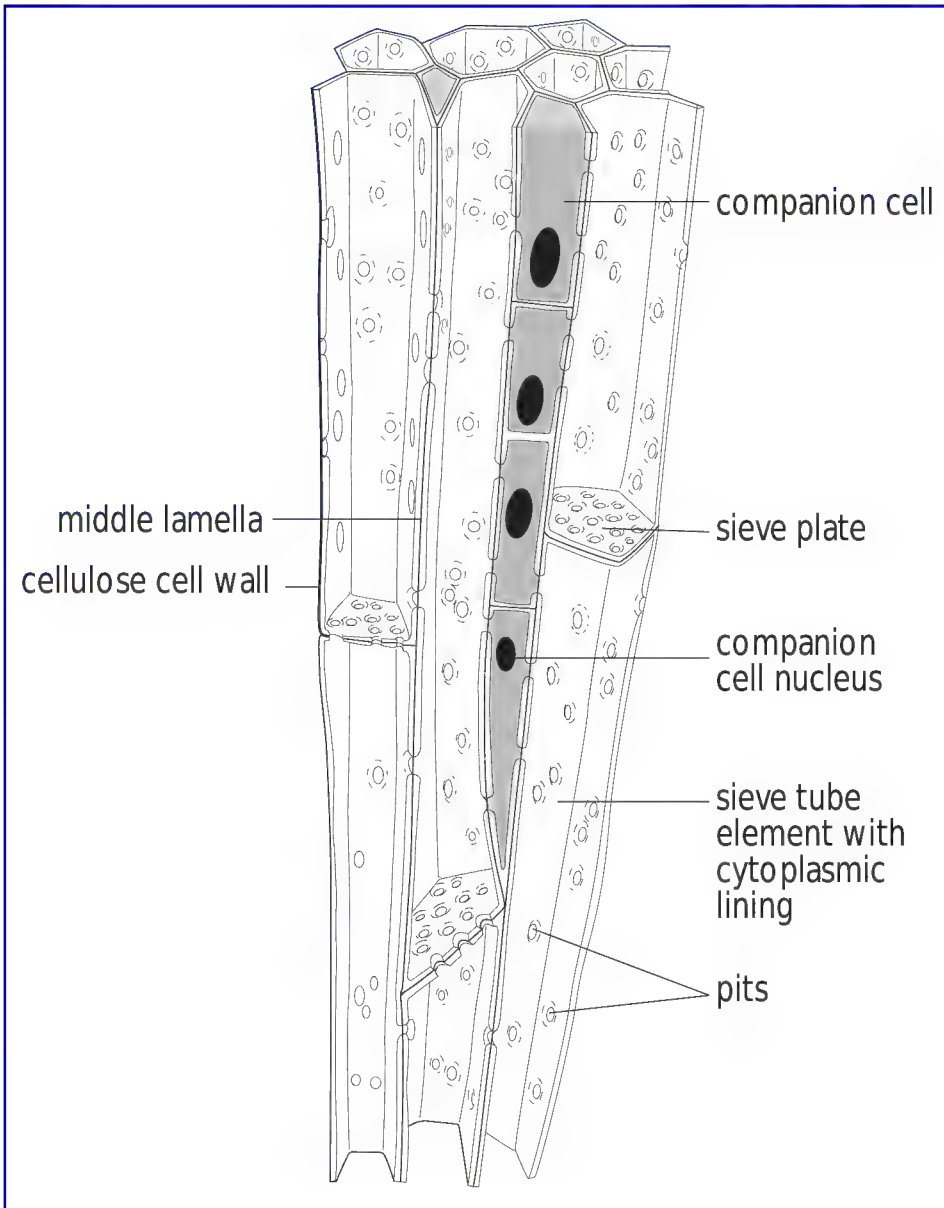


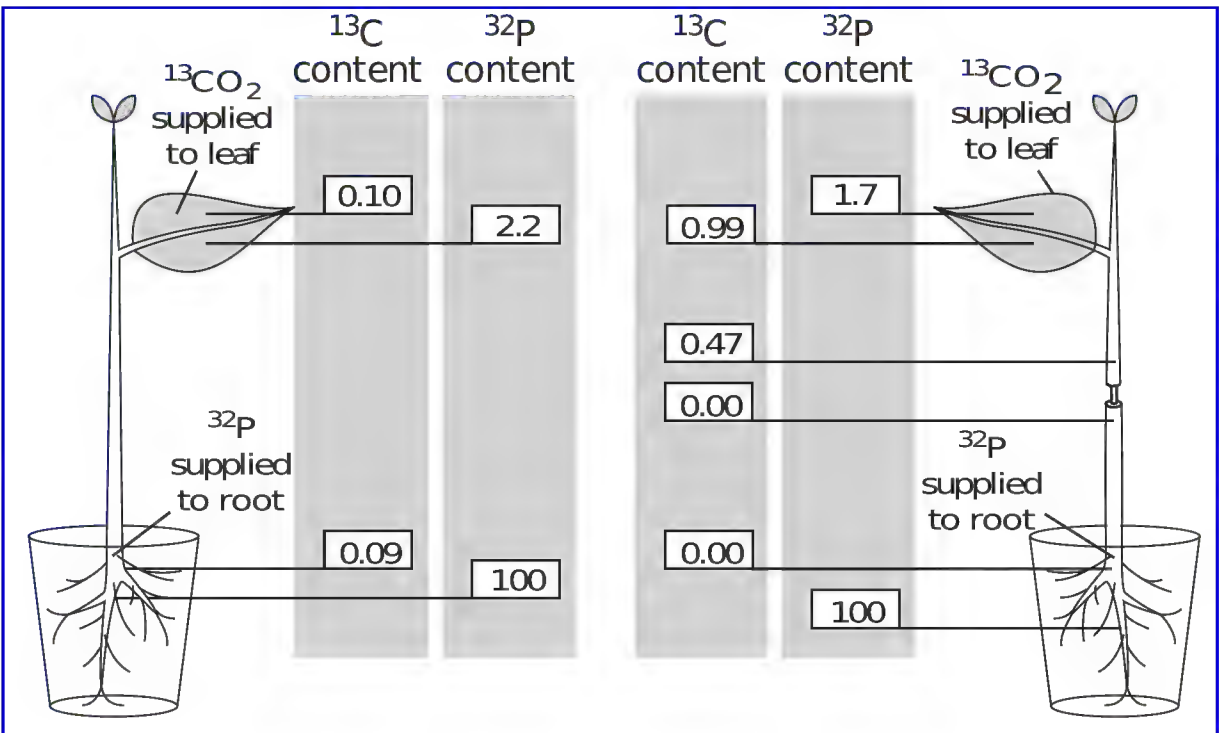
Xylem vessels showing different types of lignified thickening

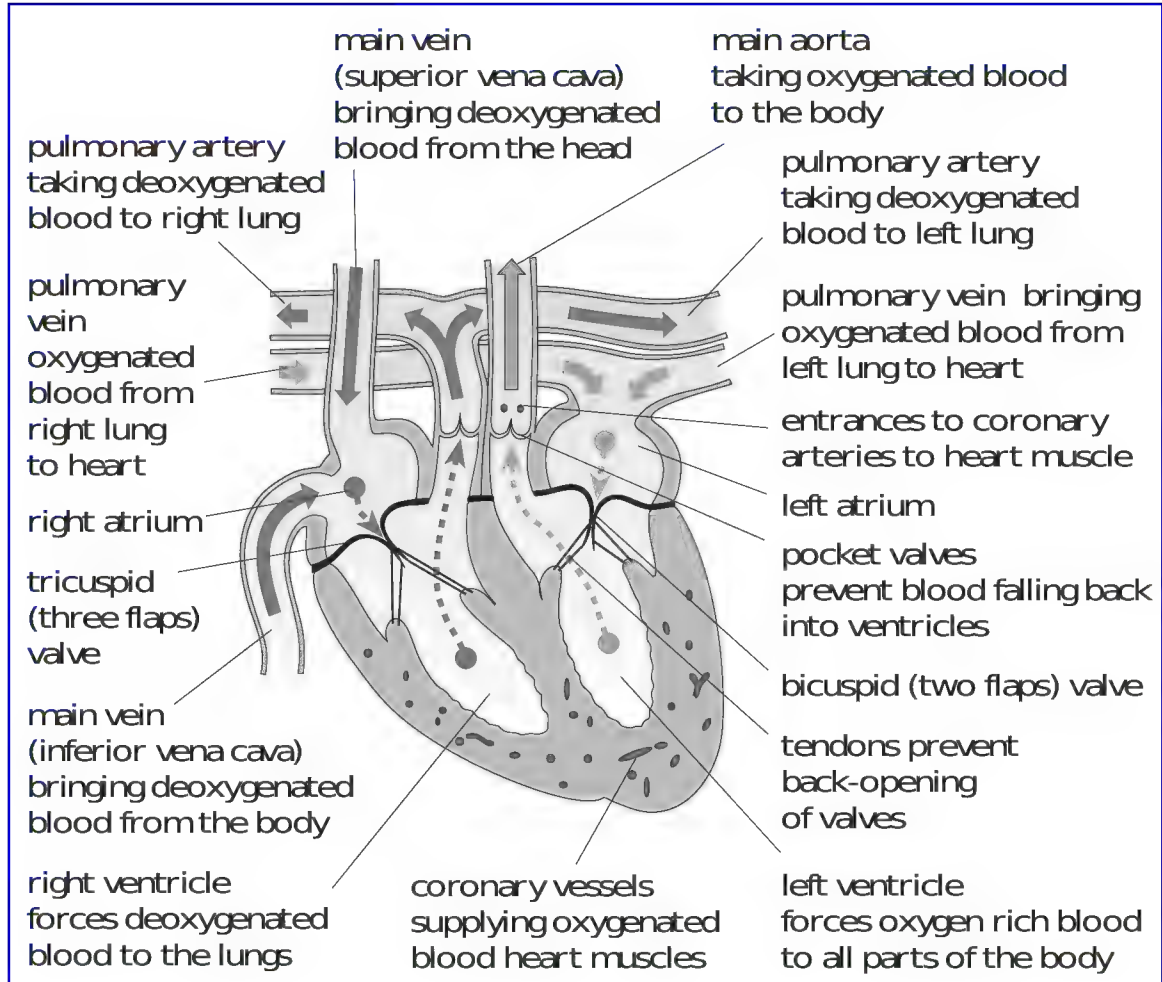


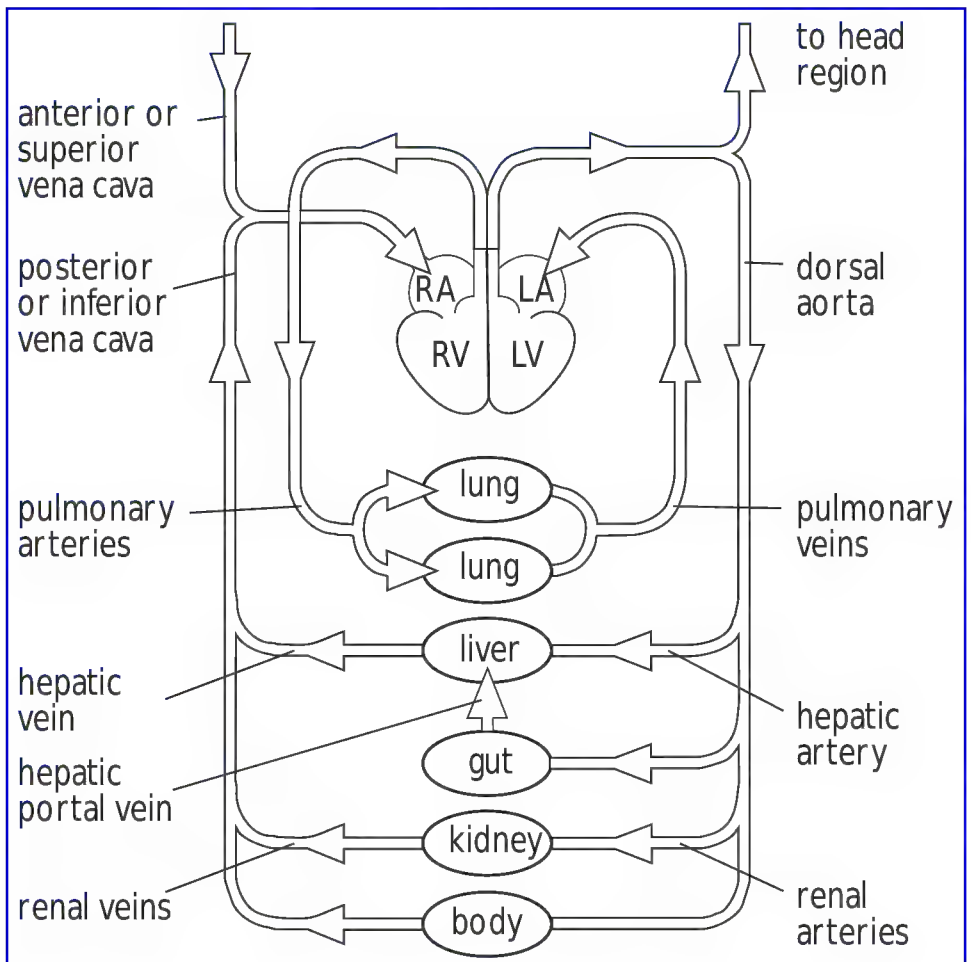
**Summary of structure of sieve tube elements
and companion cells in phloem**

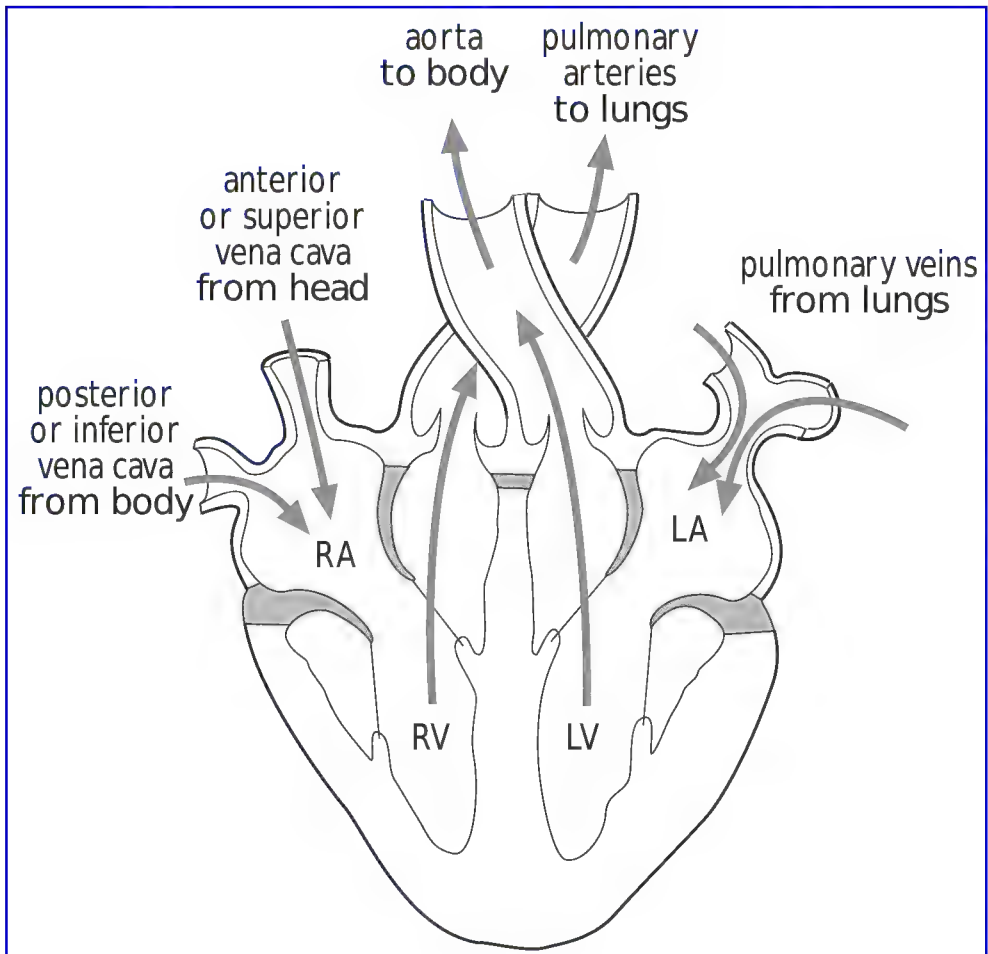
OHT Master 10

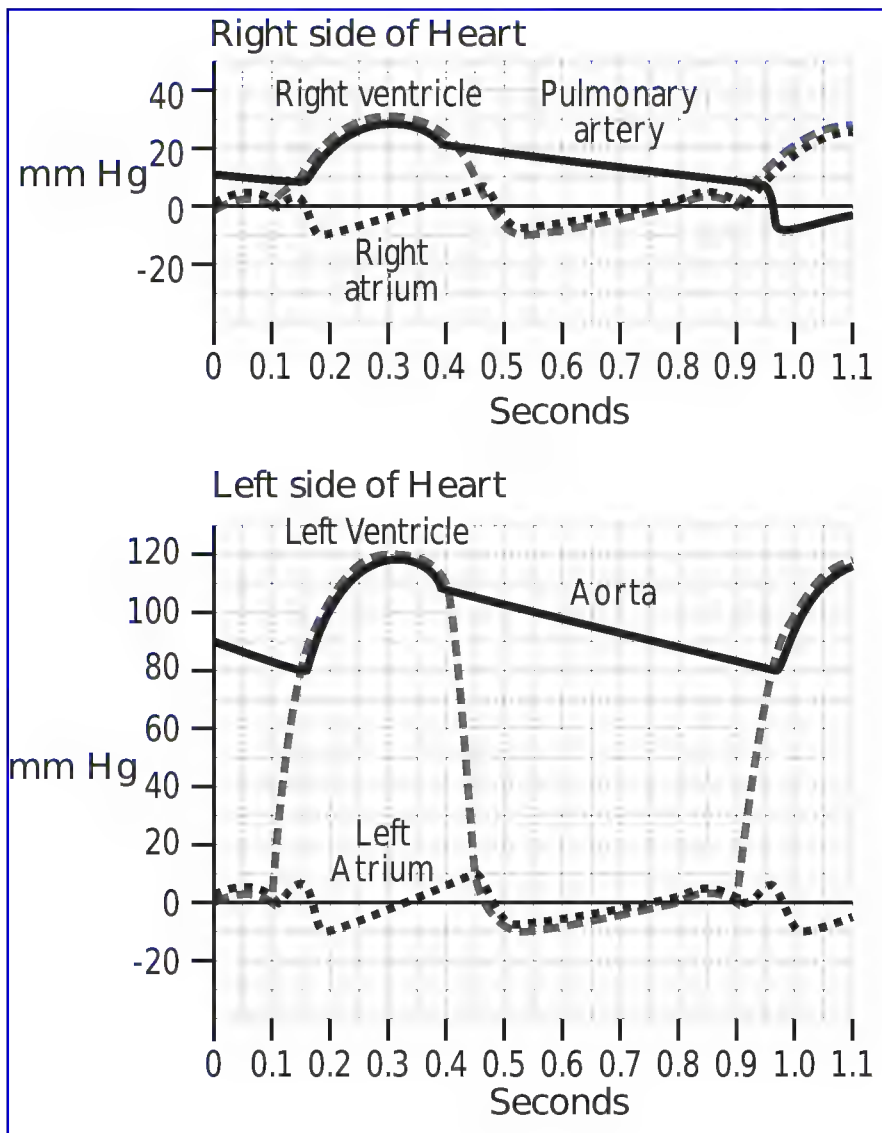


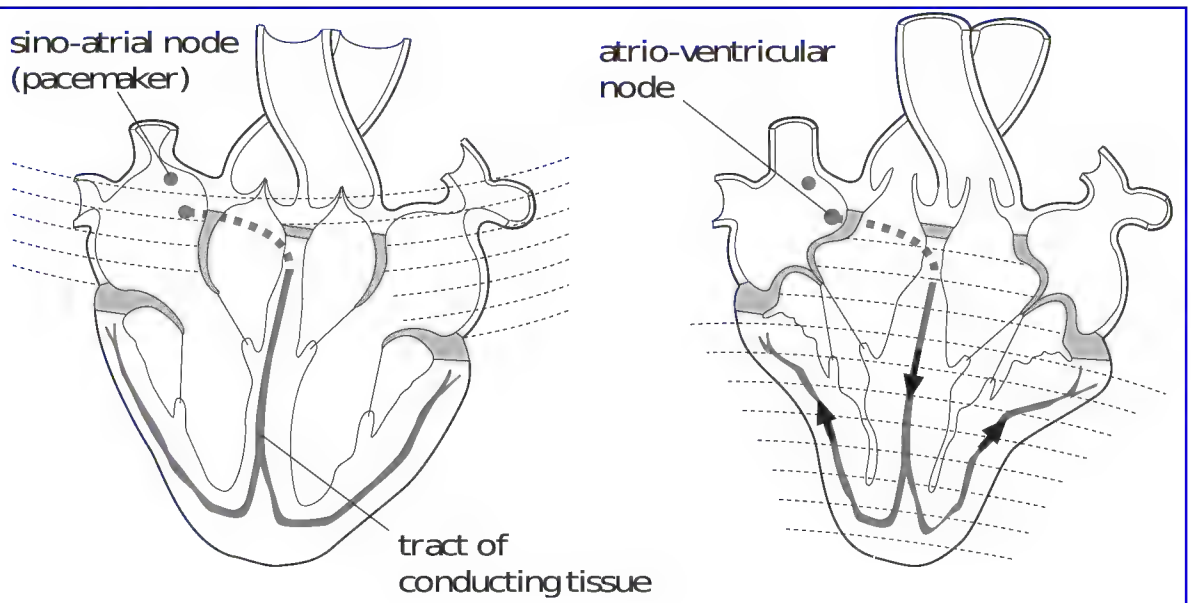


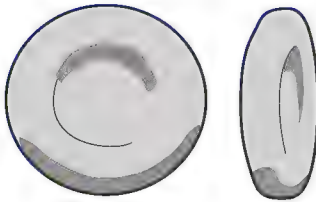








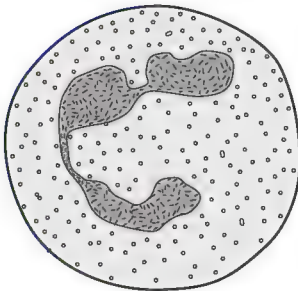




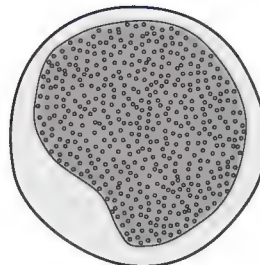
Red cell



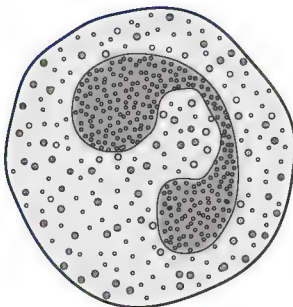
Platelets



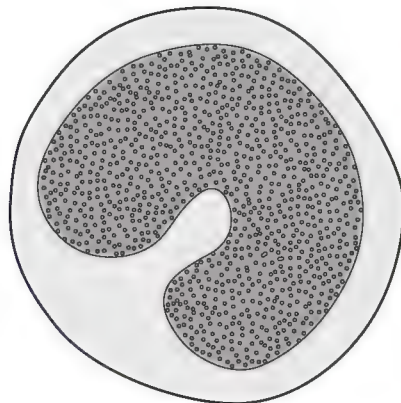
Neutrophil



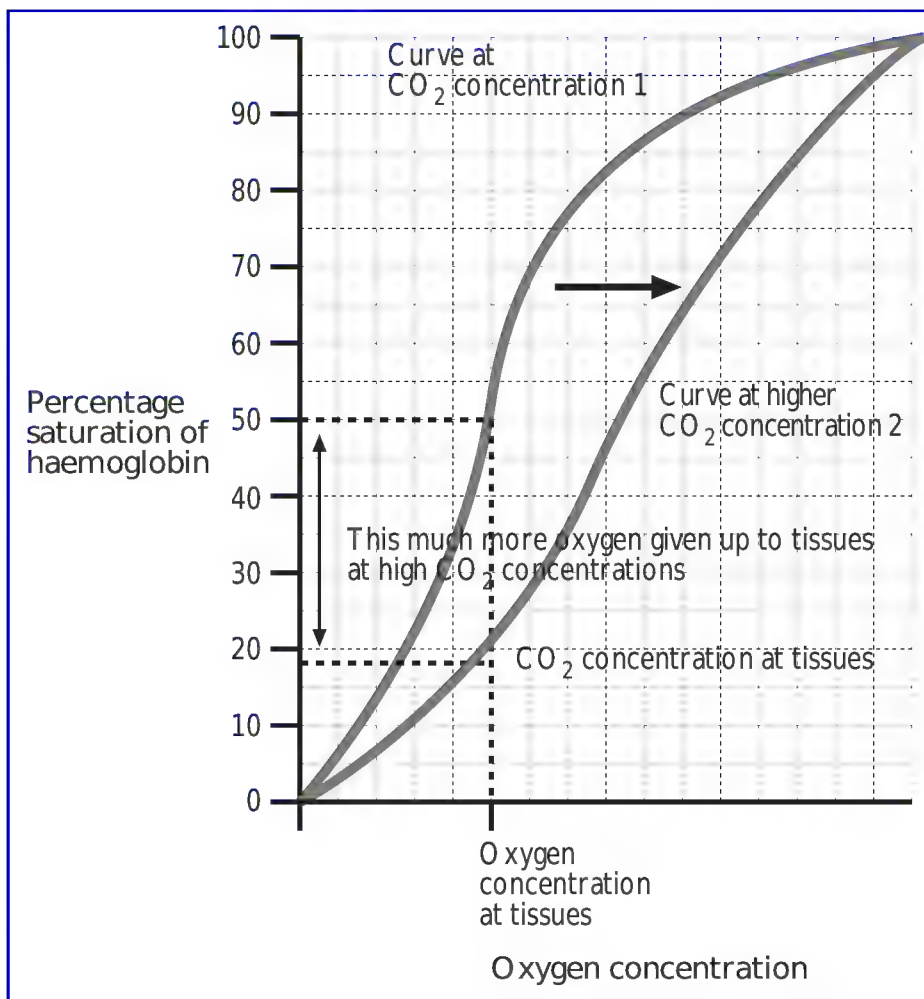
Lymphocyte

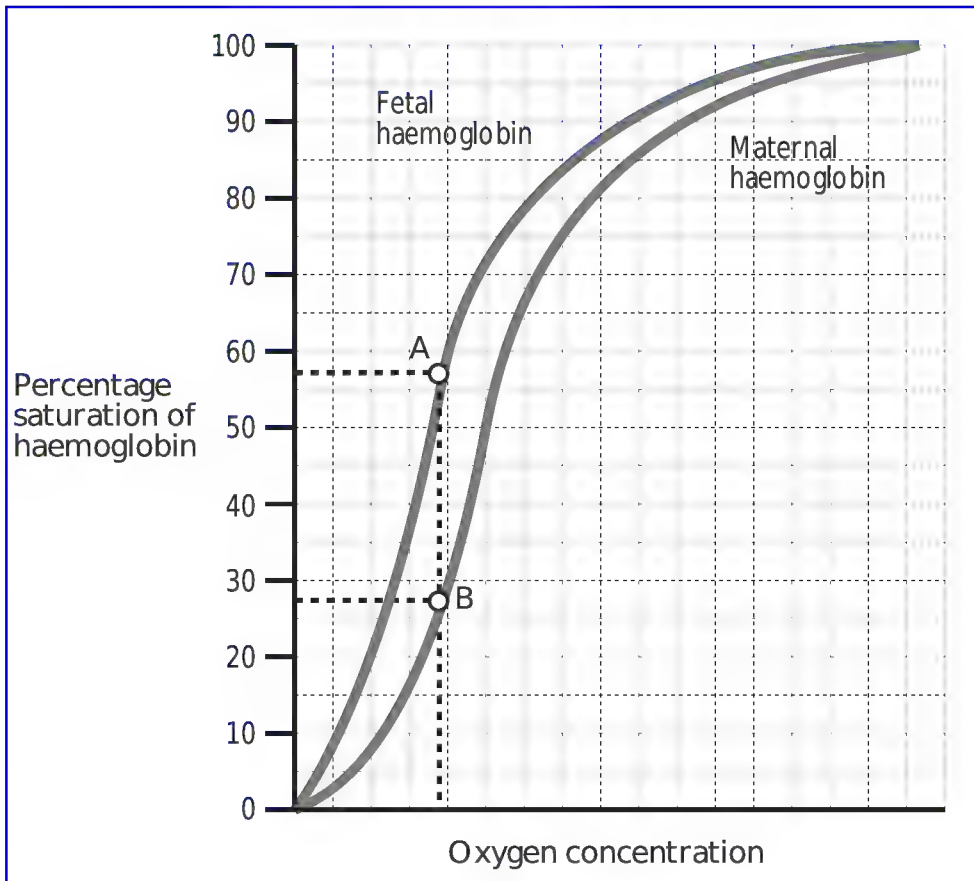


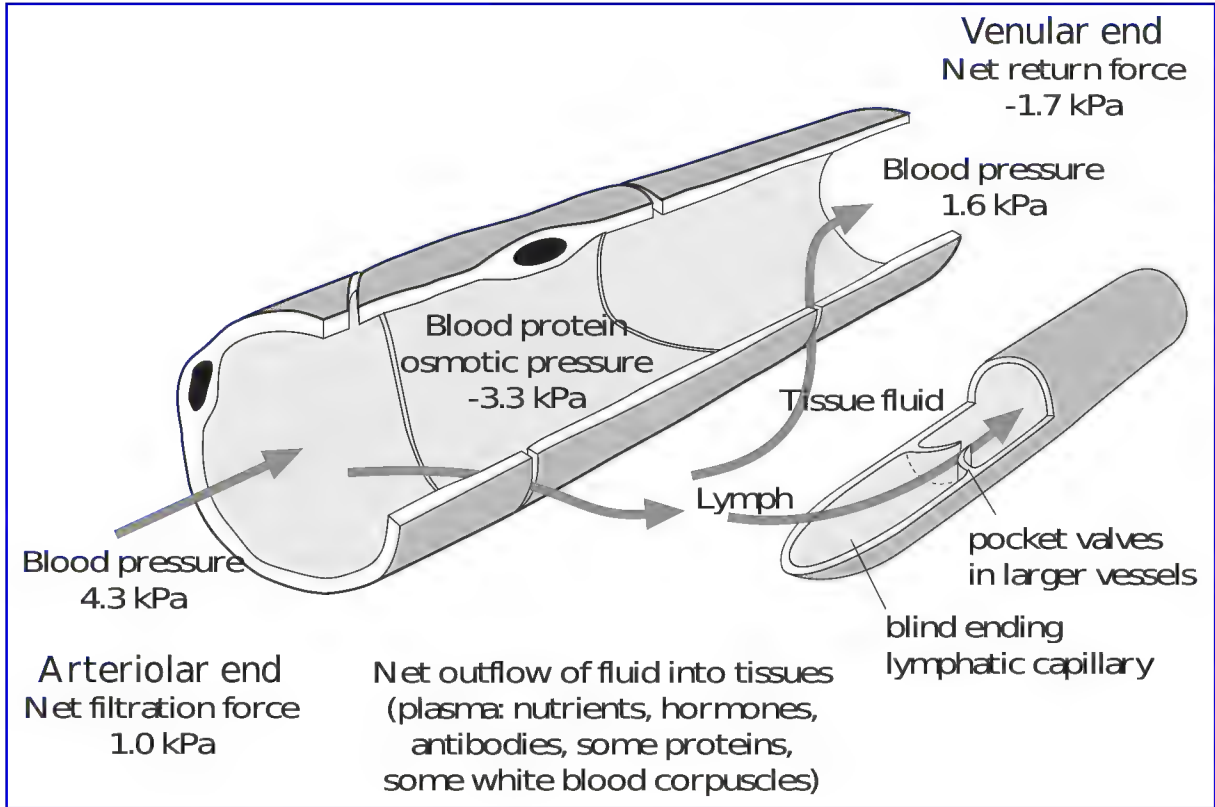
Eosinophil

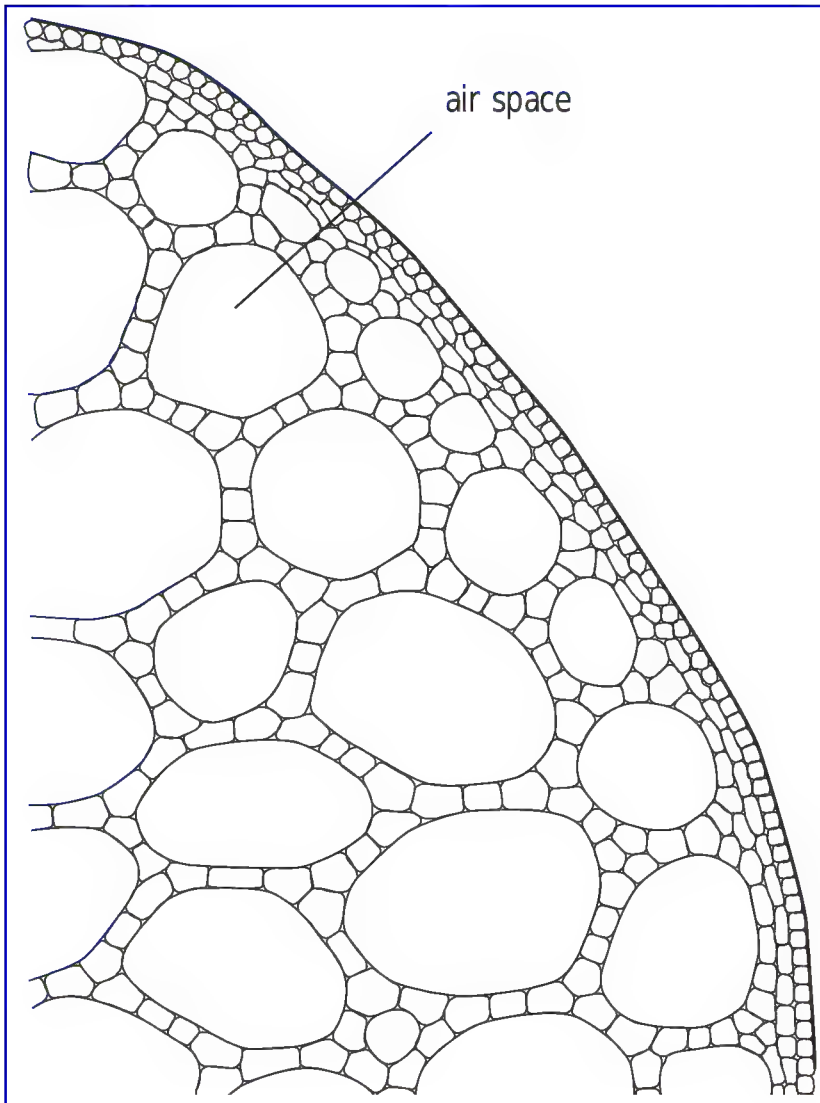


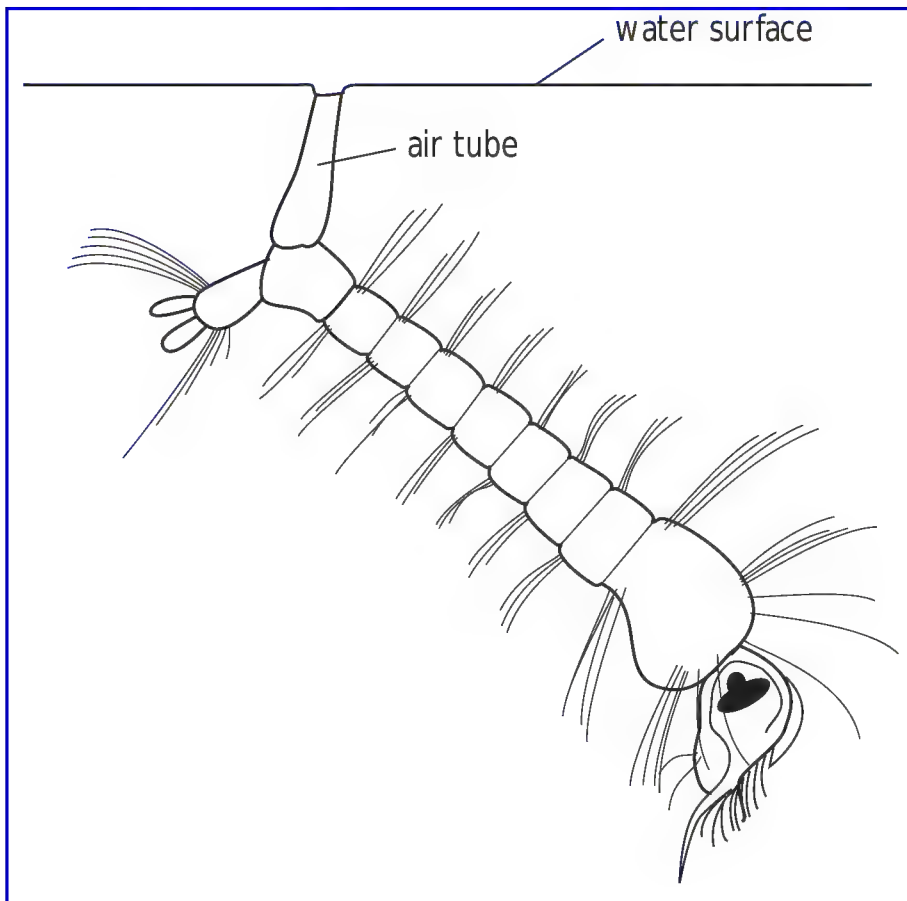
Monocyte

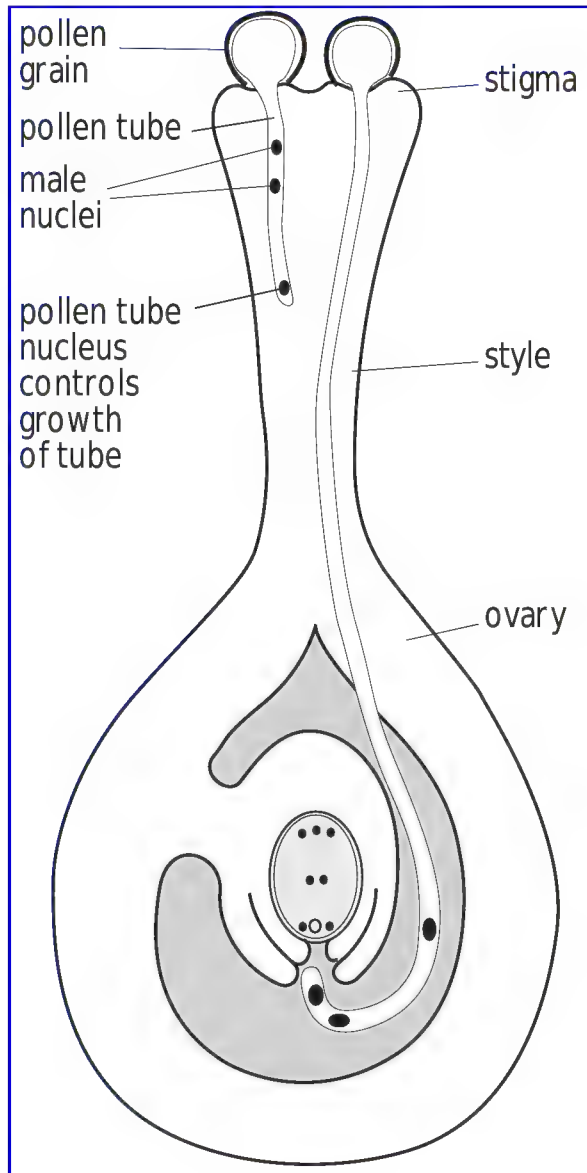


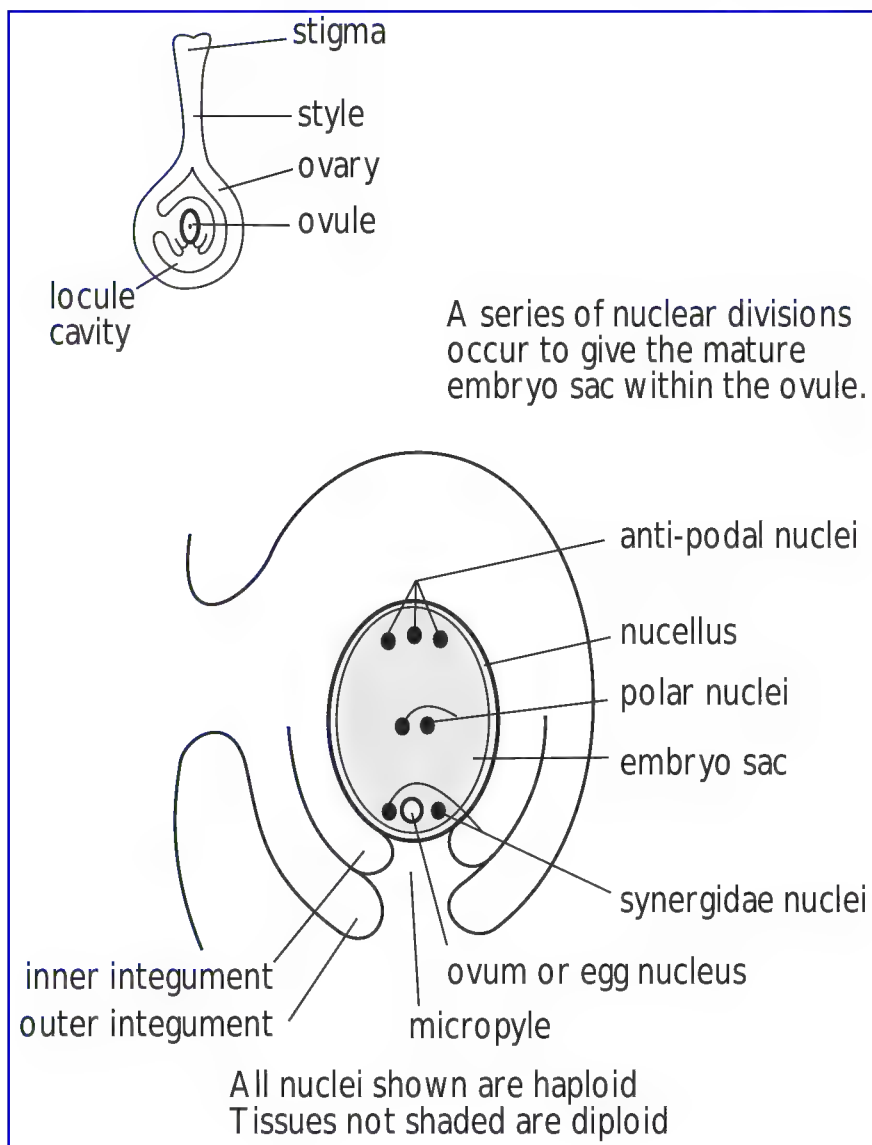






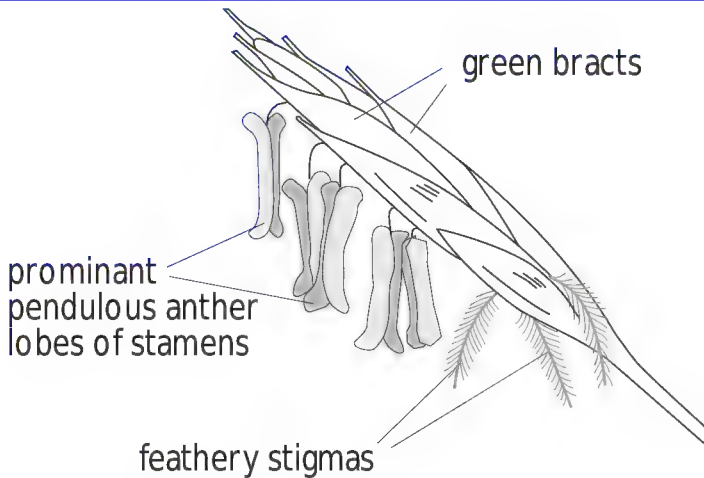






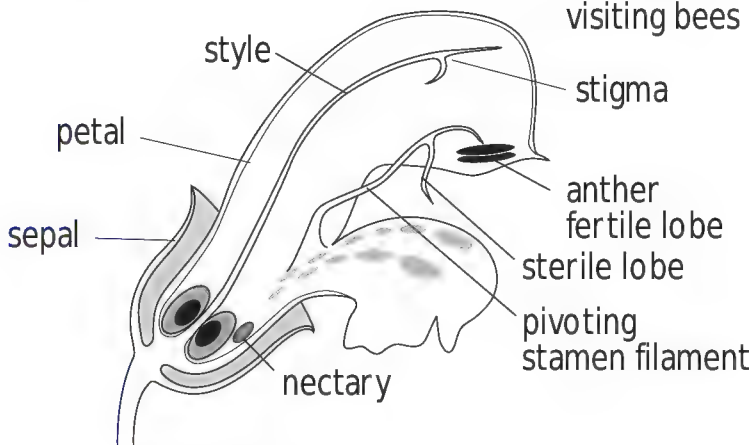
**Wind pollinated flower
and insect pollinated flower**

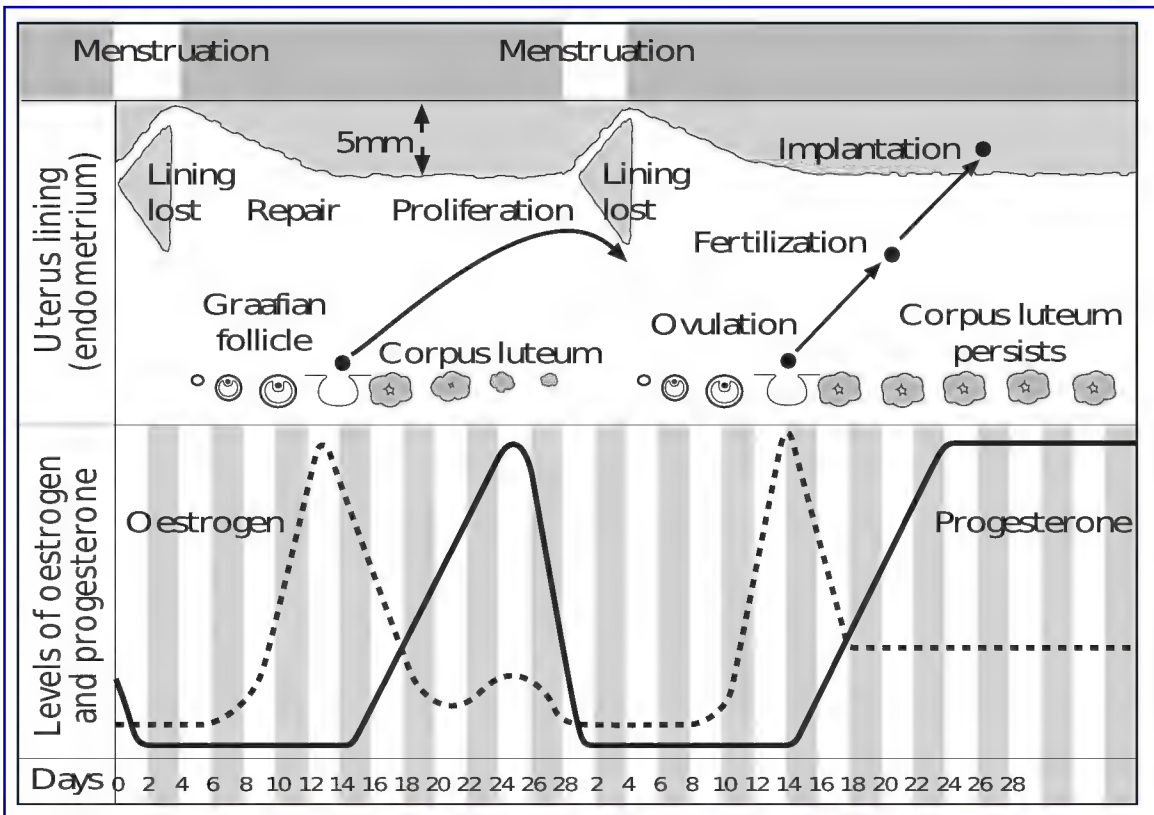
OHT Master 45

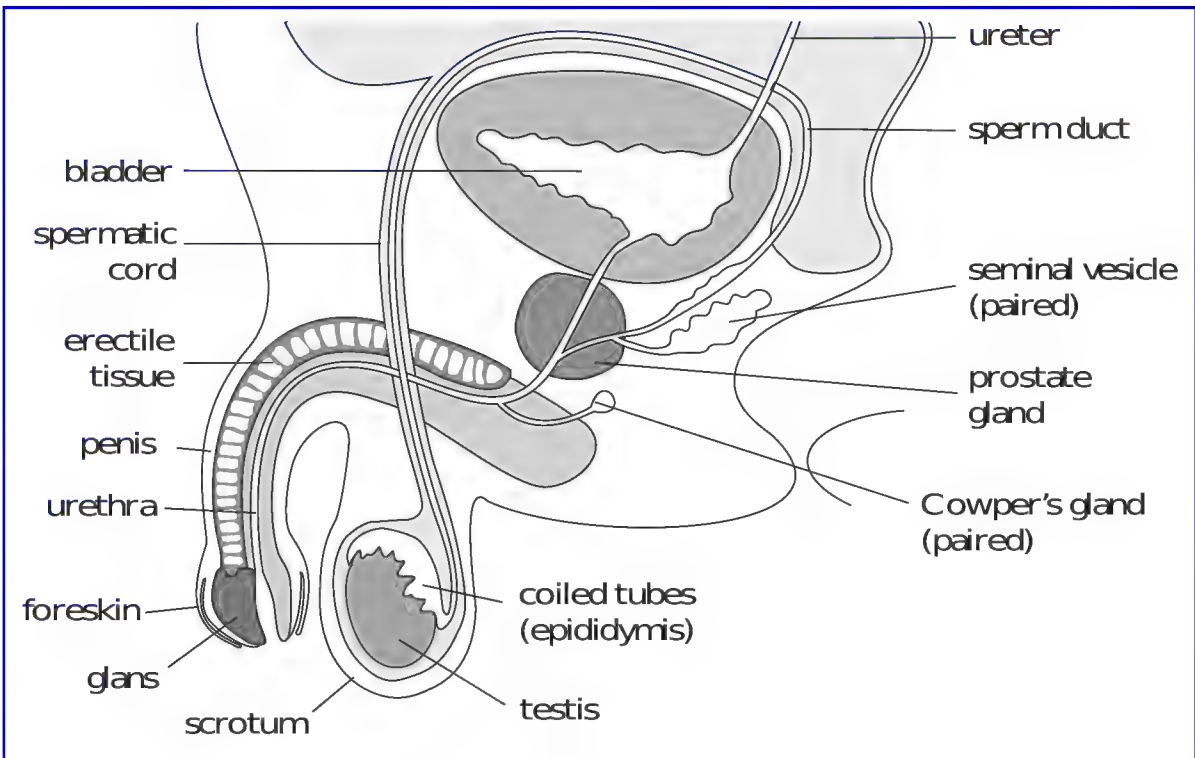


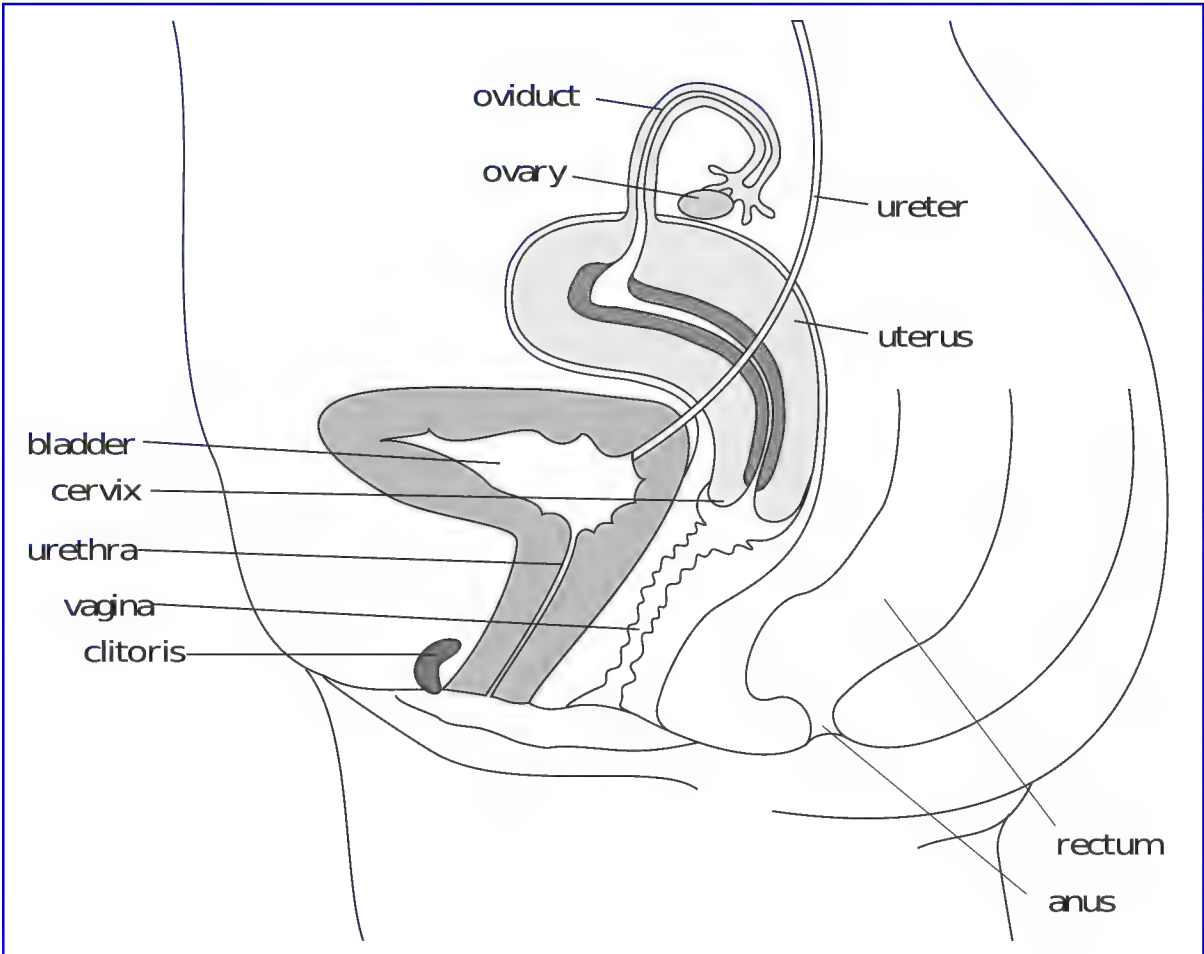
Bee pushes sterile lobe
and fertile lobe pivots
down to deposit pollen
on back of bee

Stigma projects at
a later stage and
picks up pollen
from later
visiting bees

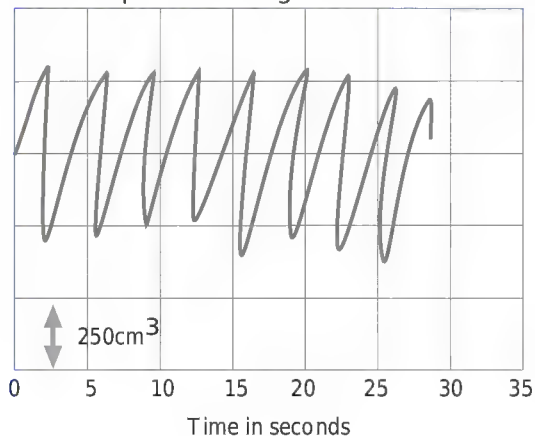




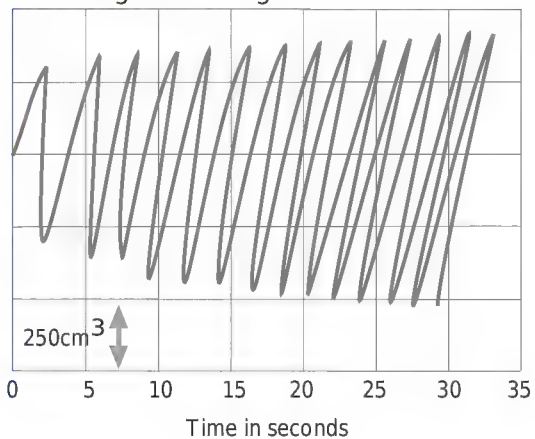




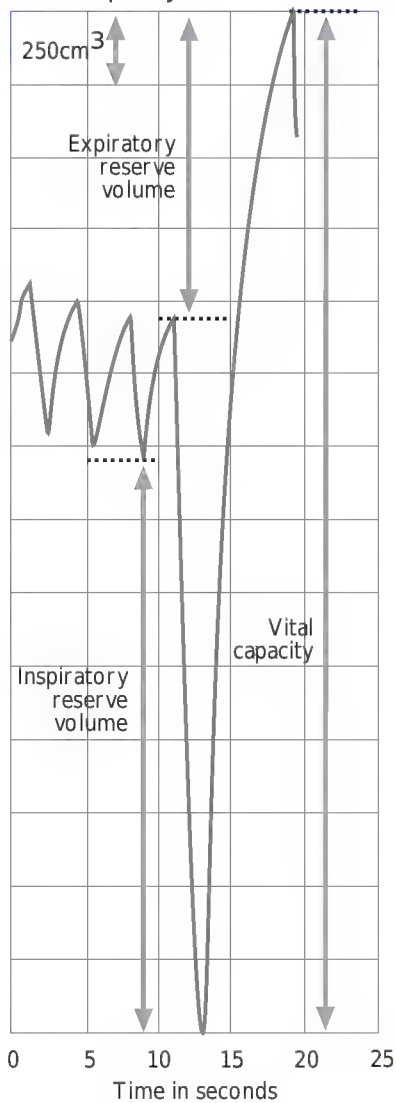
Normal quiet breathing at rest

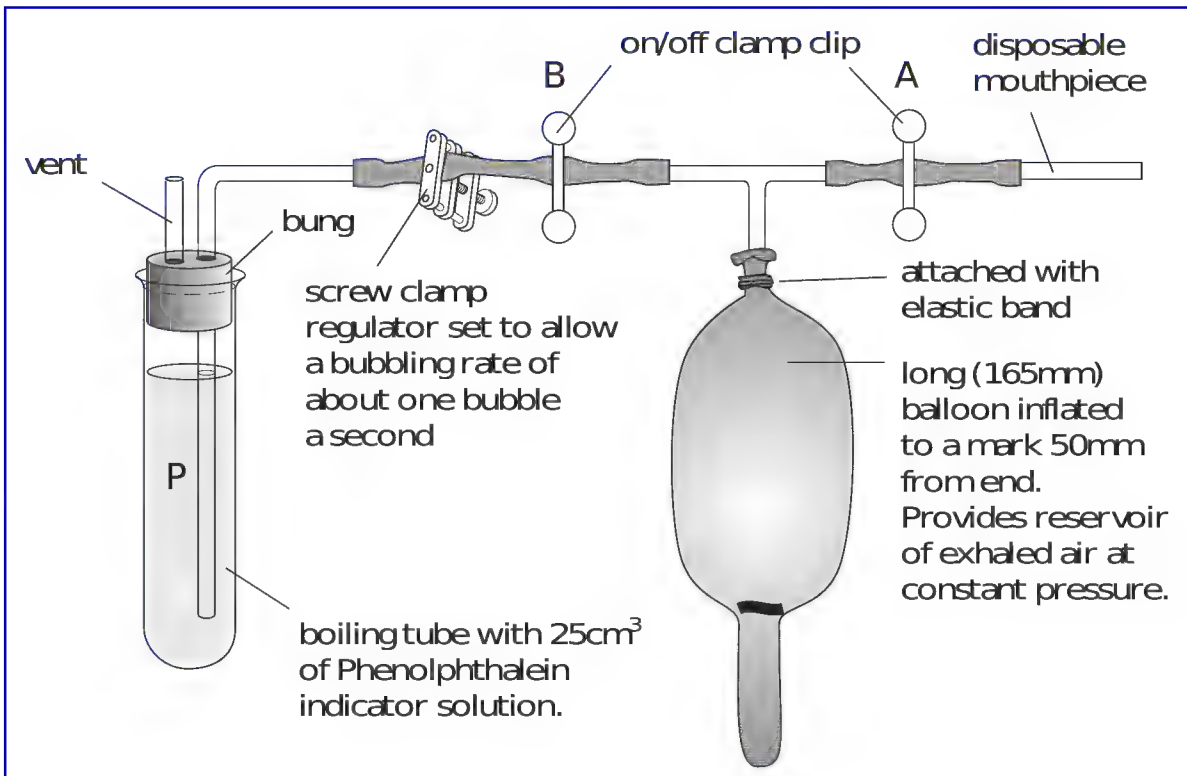


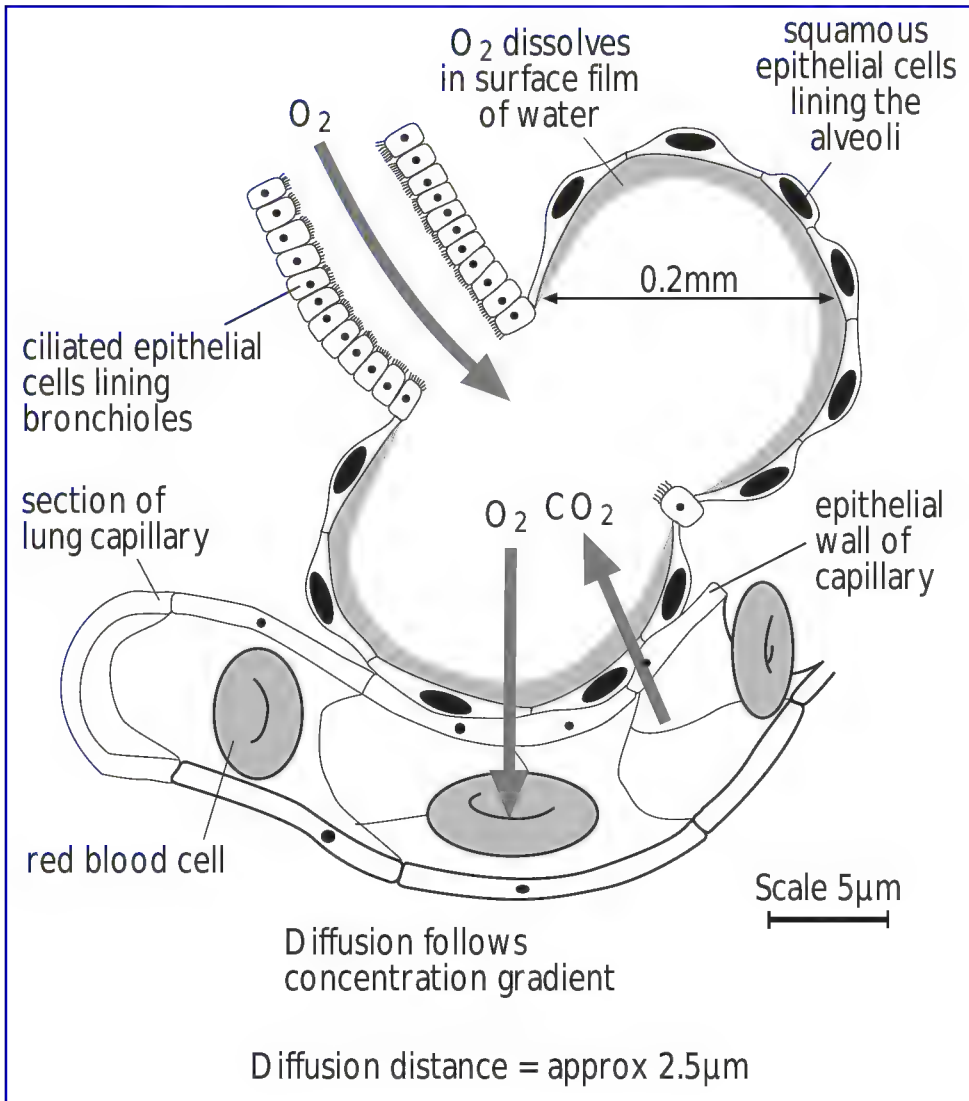
Breathing at start of gentle exercise



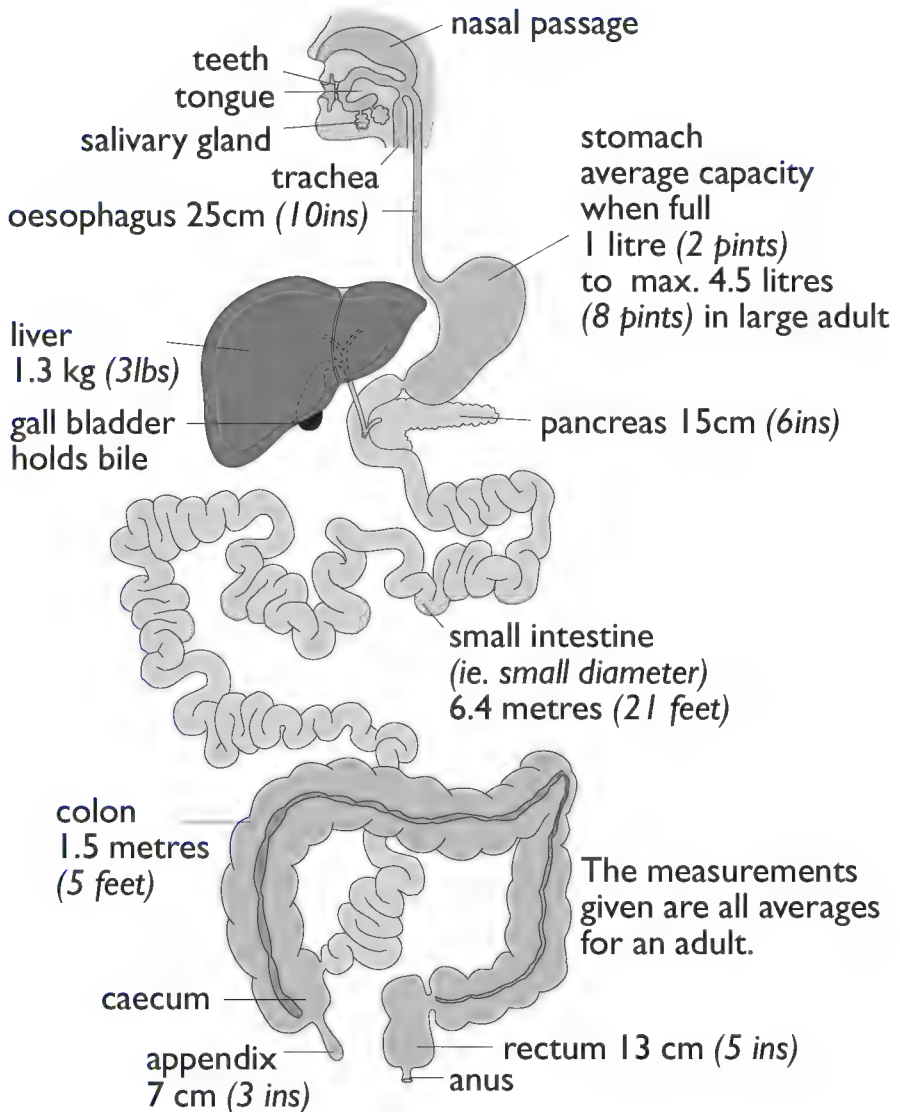
Vital Capacity

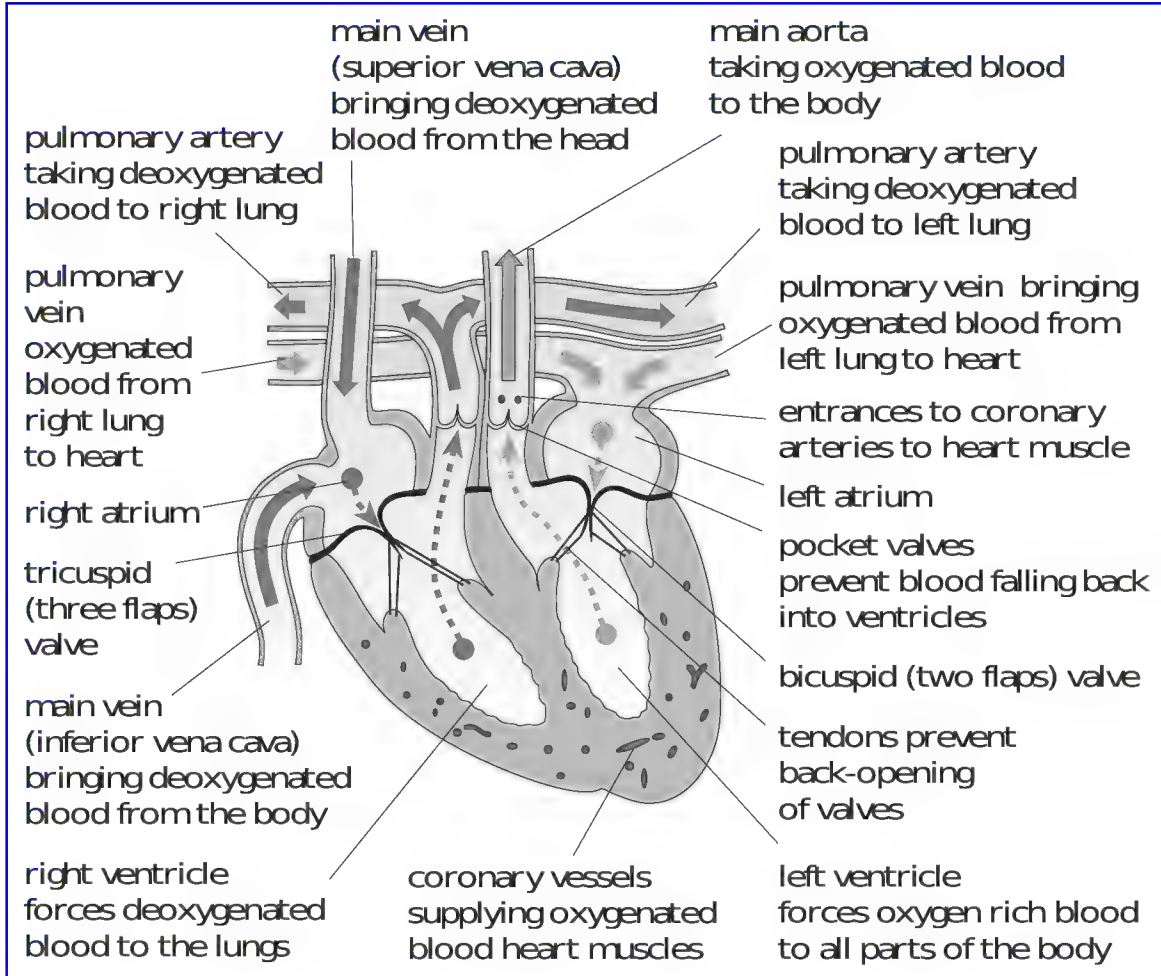


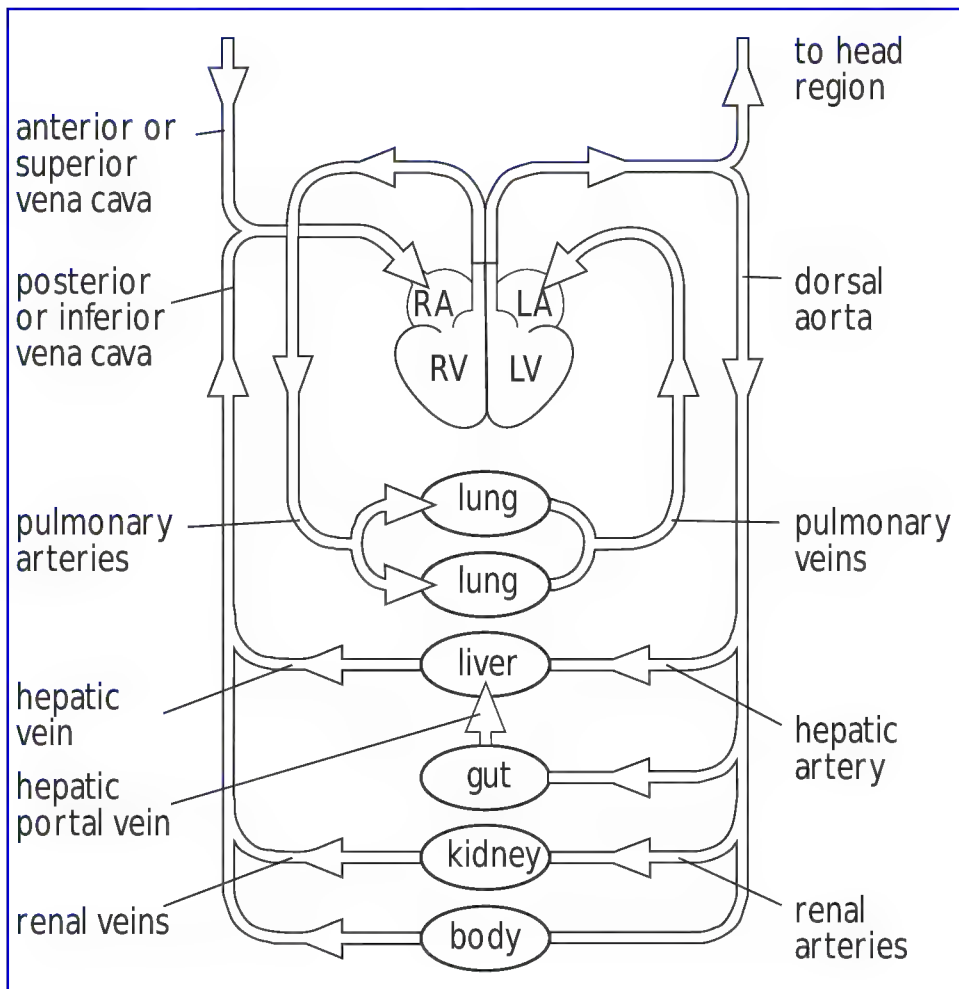


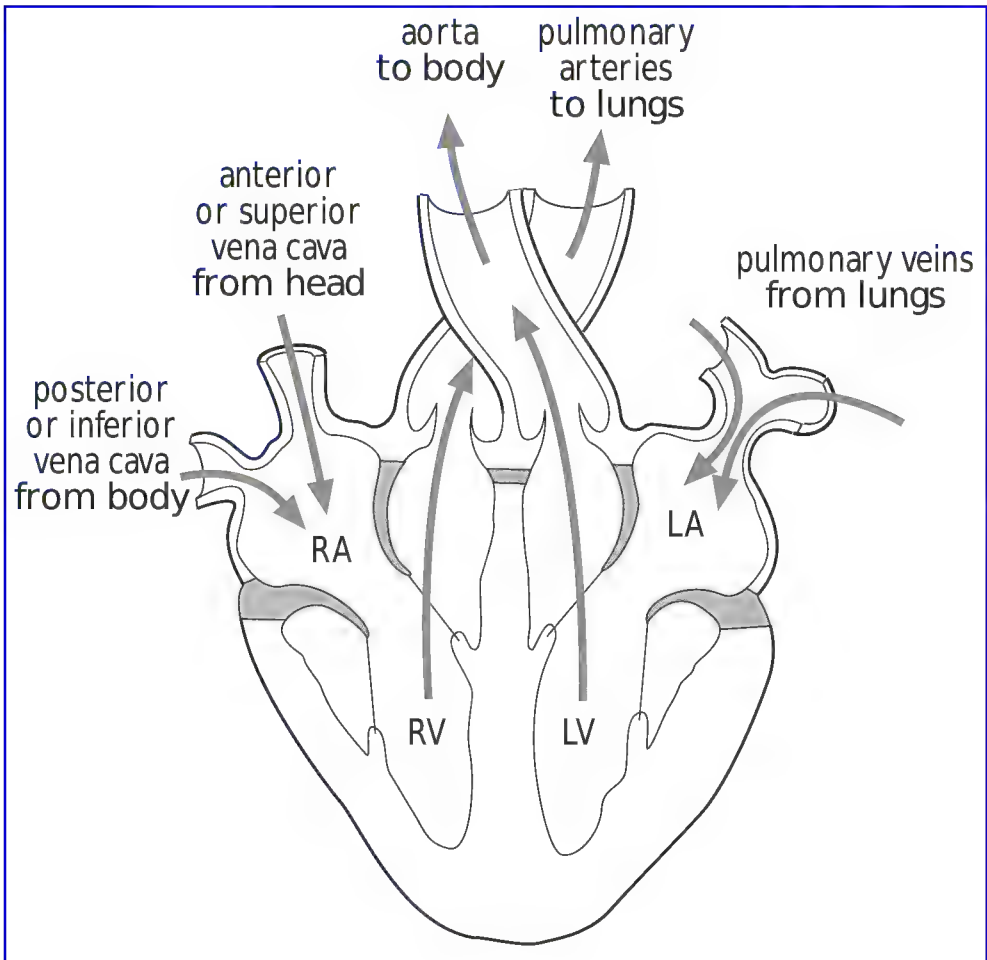


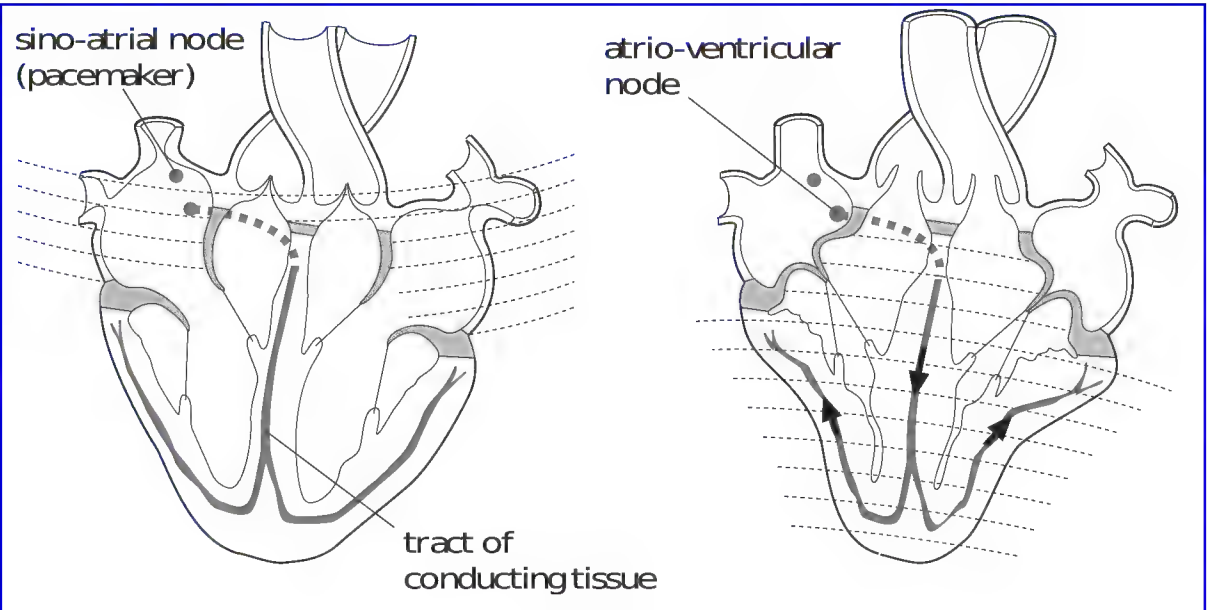
Digestive System Displaced

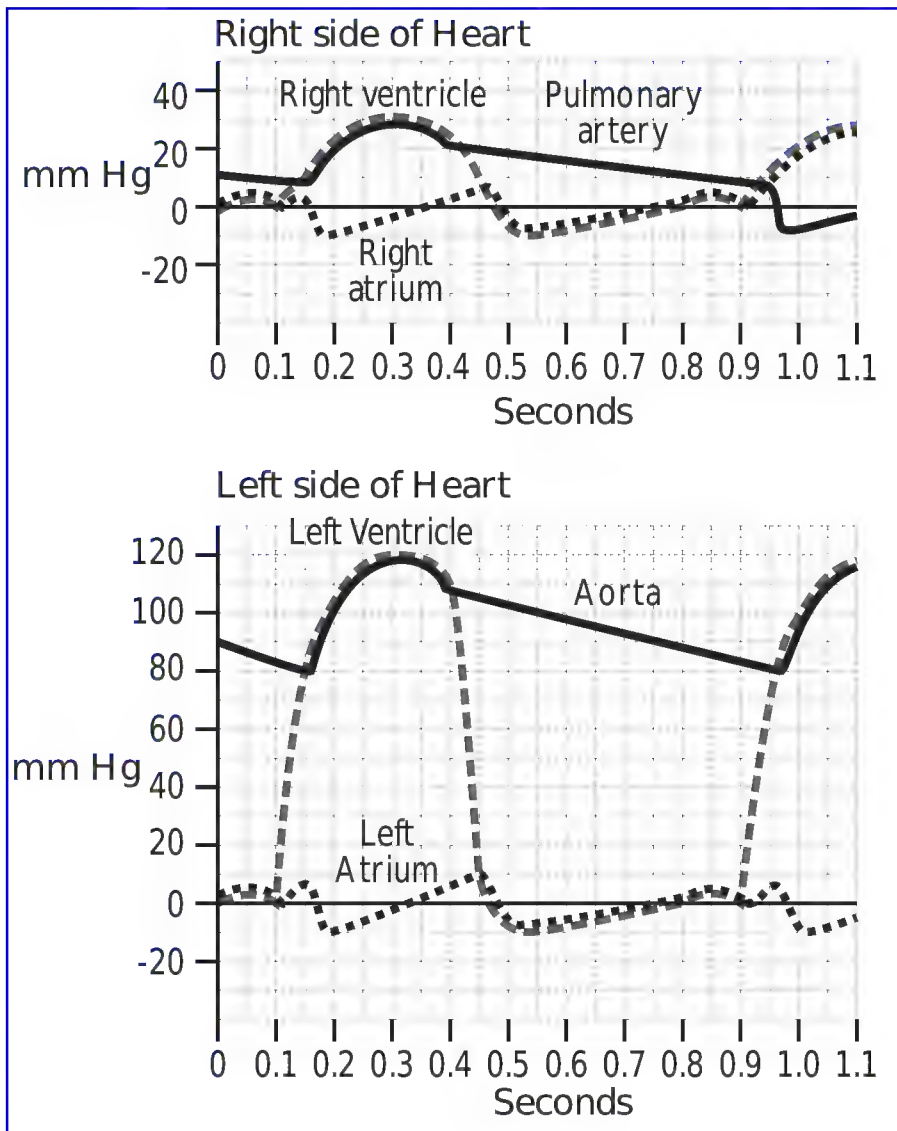


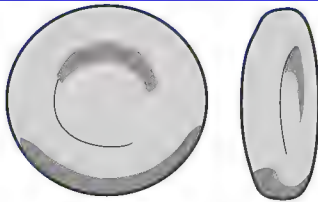








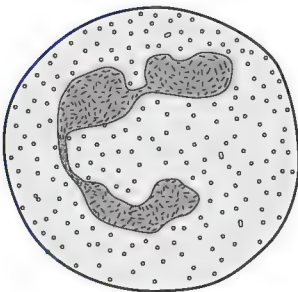




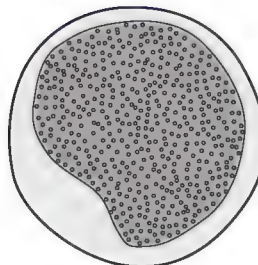
Red cell



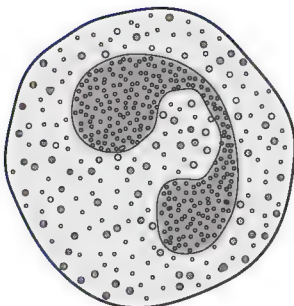
Platelets



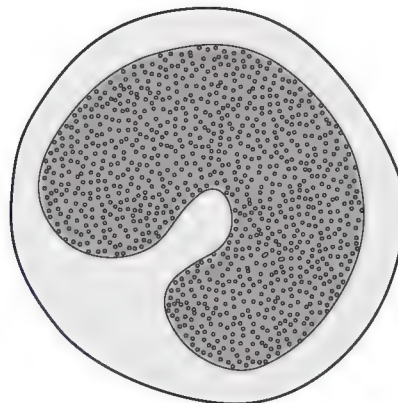
Neutrophil



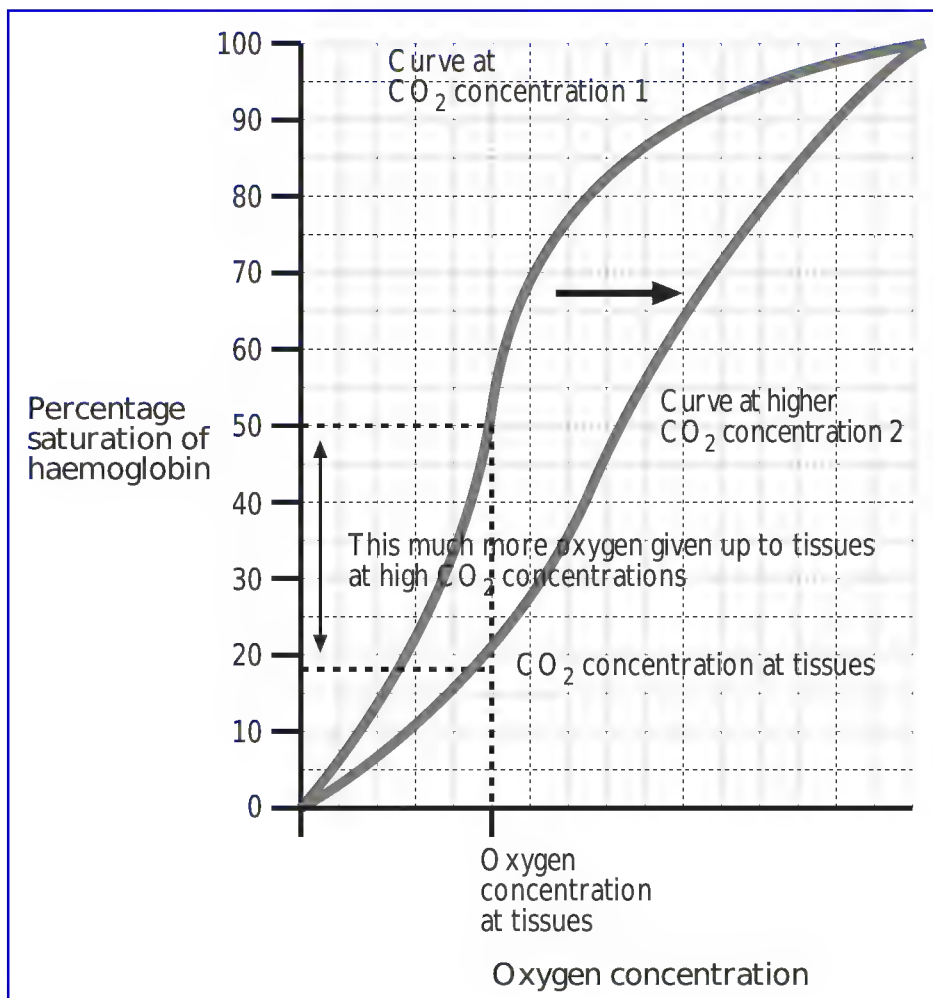
Lymphocyte

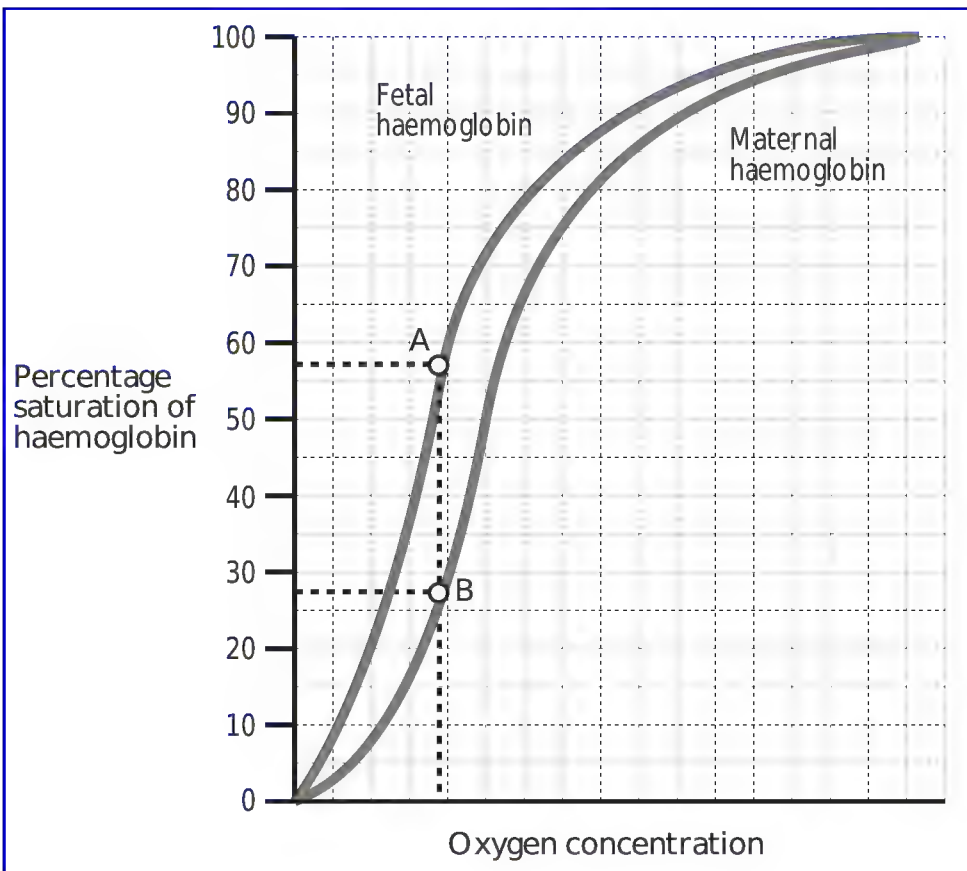


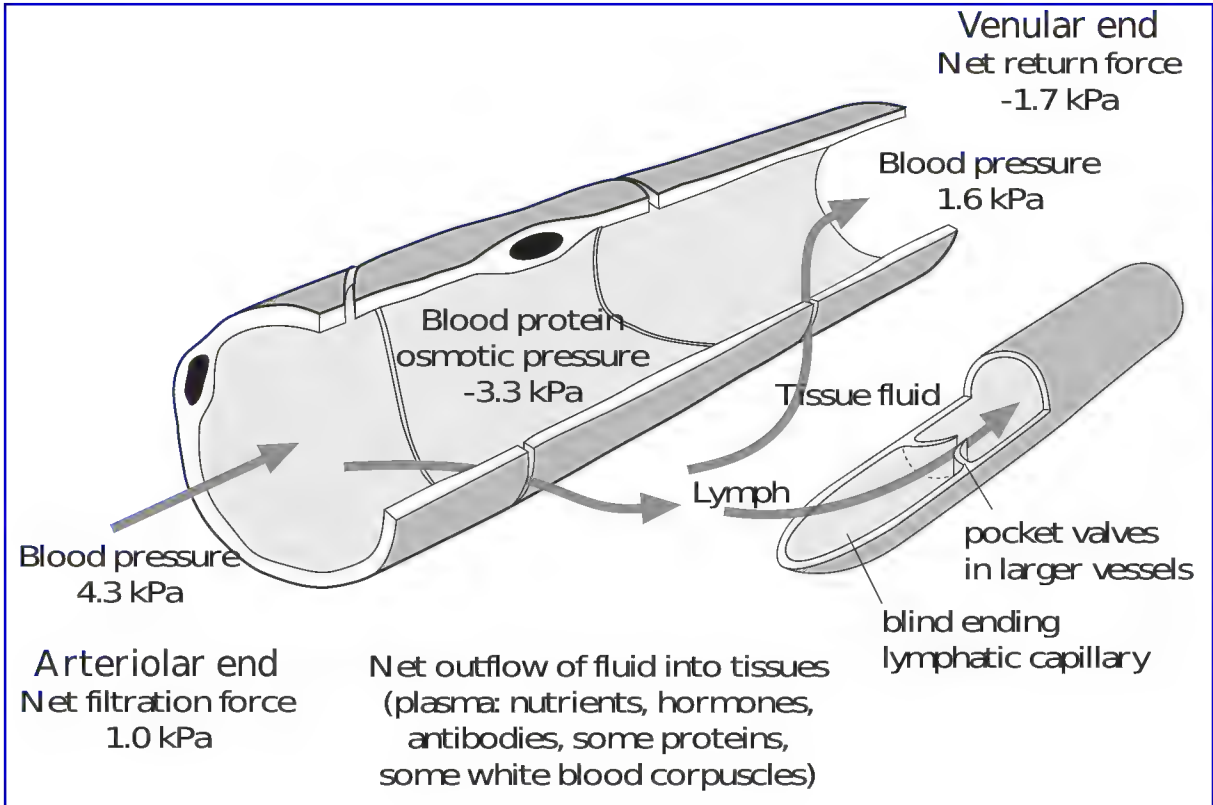
Eosinophil

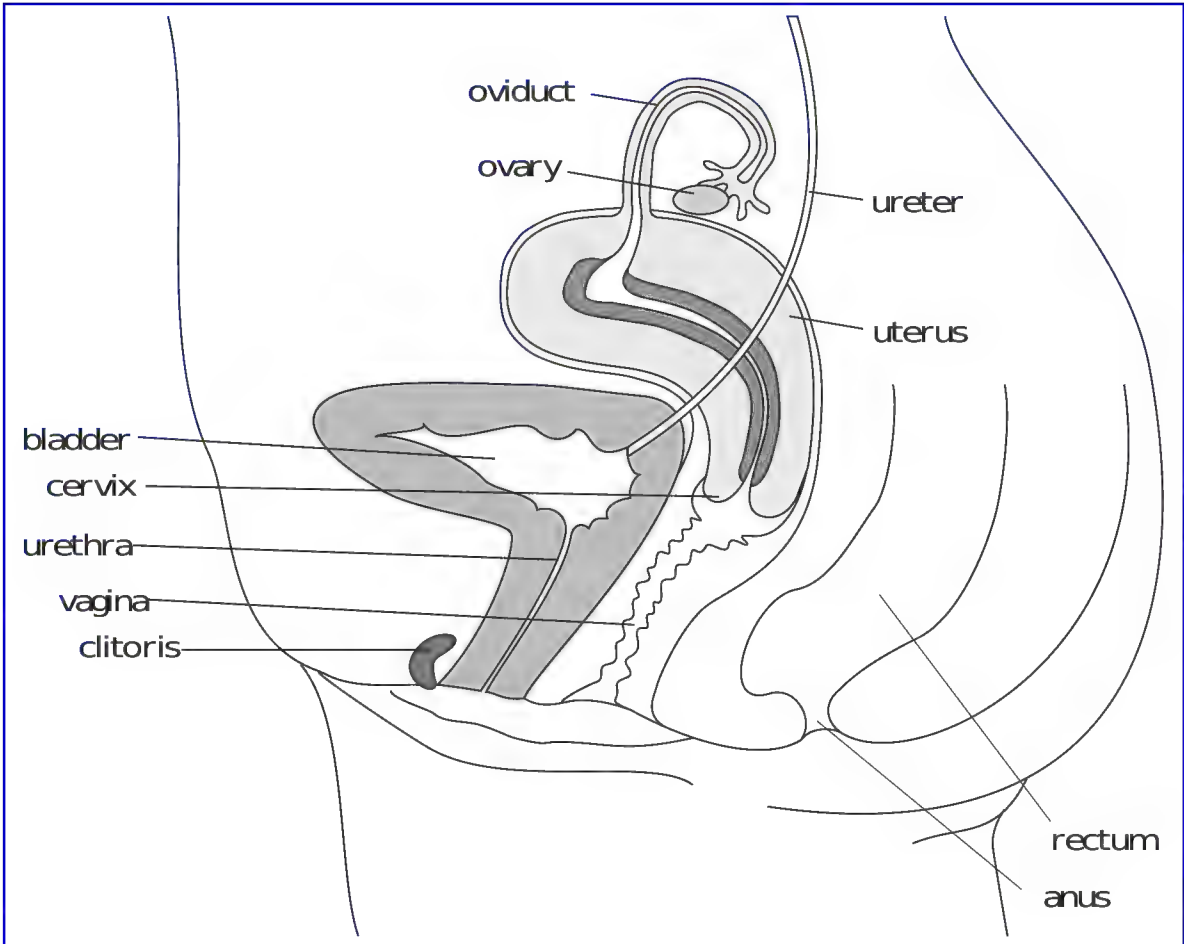


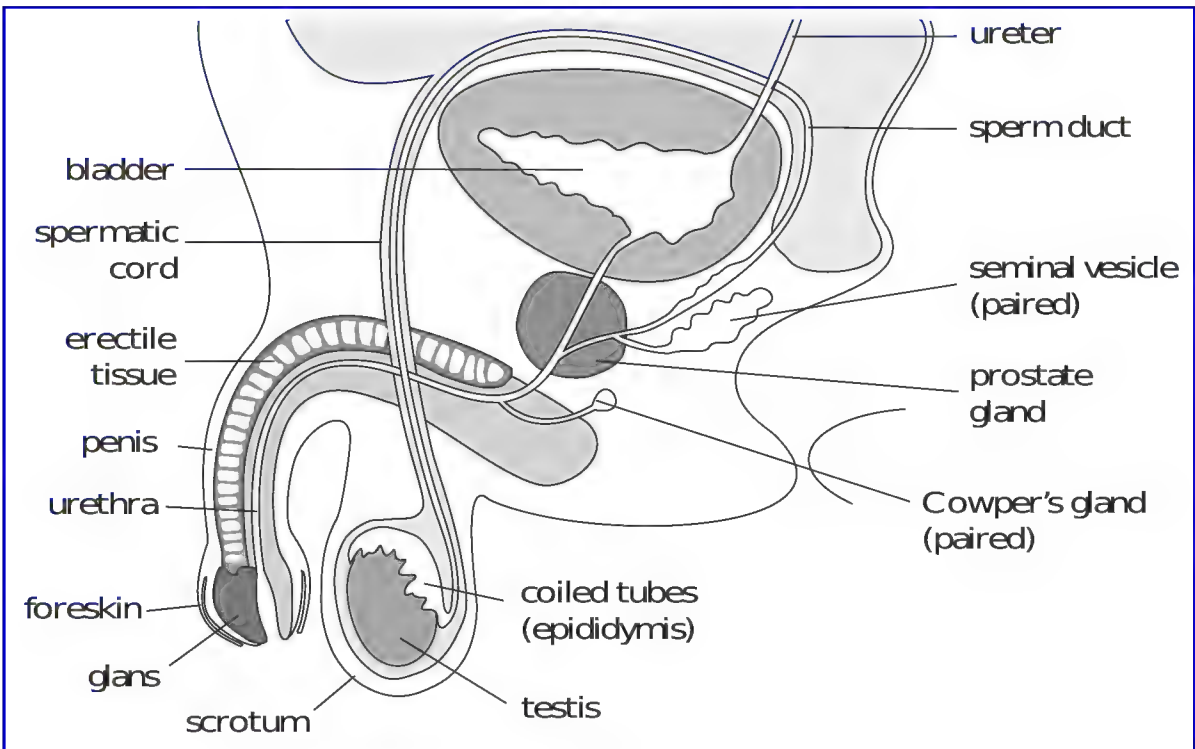
Monocyte

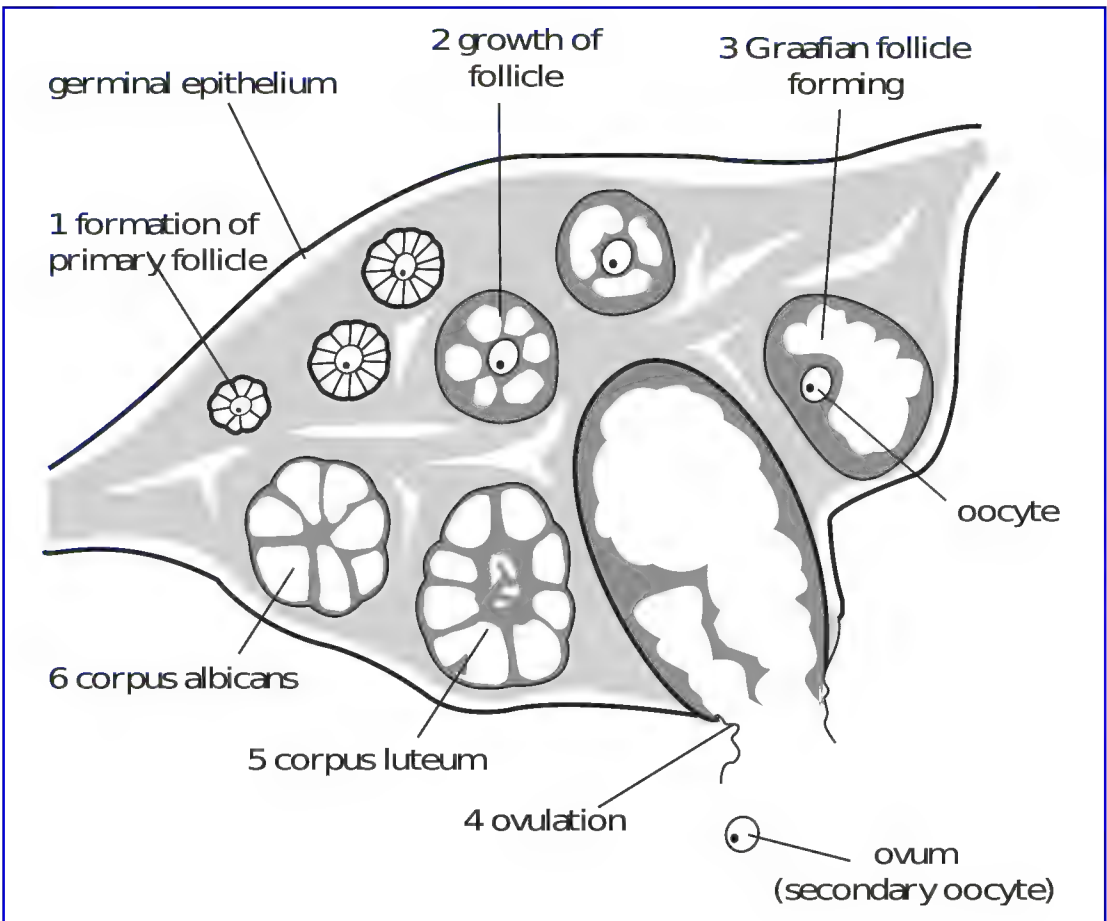


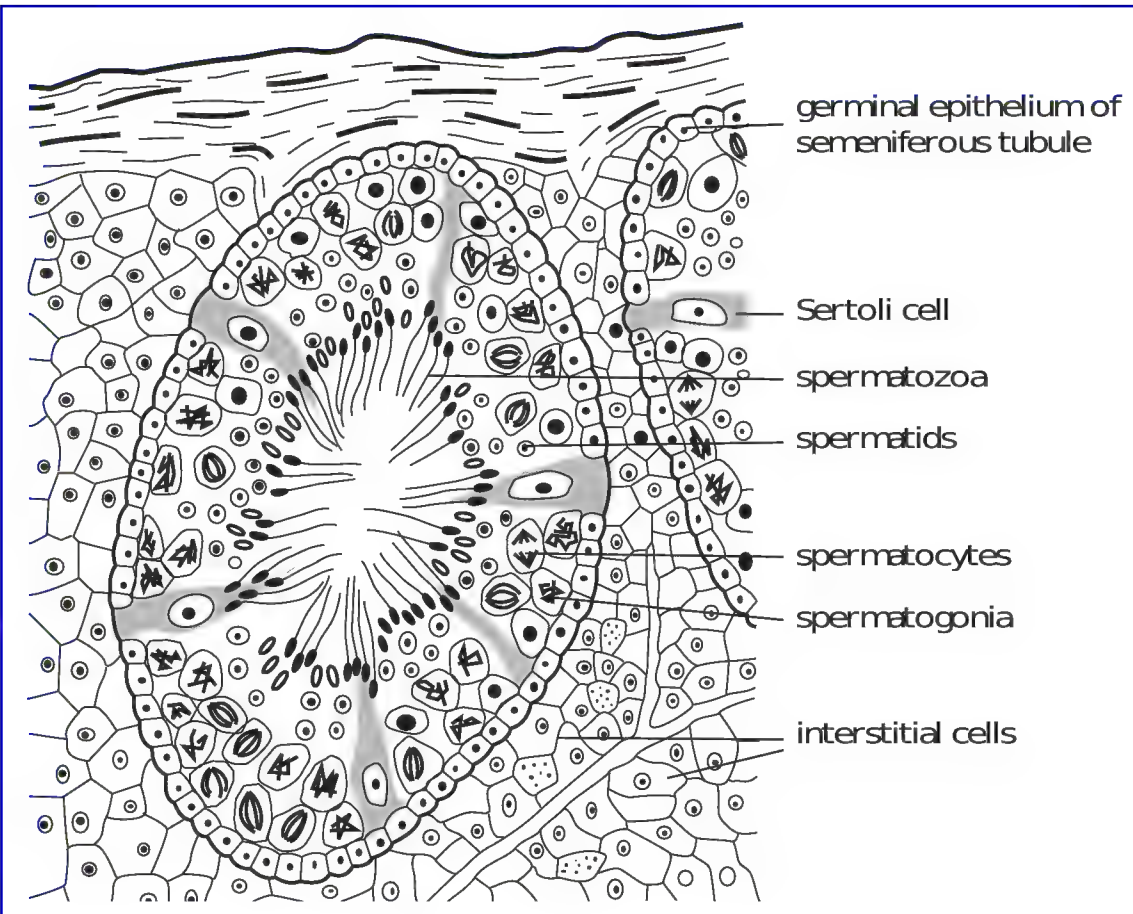






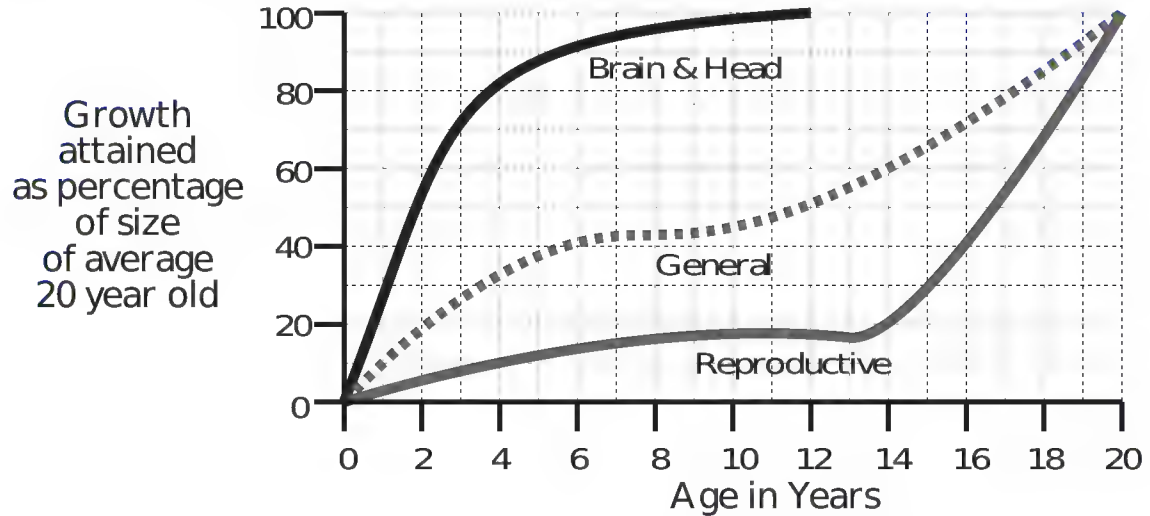


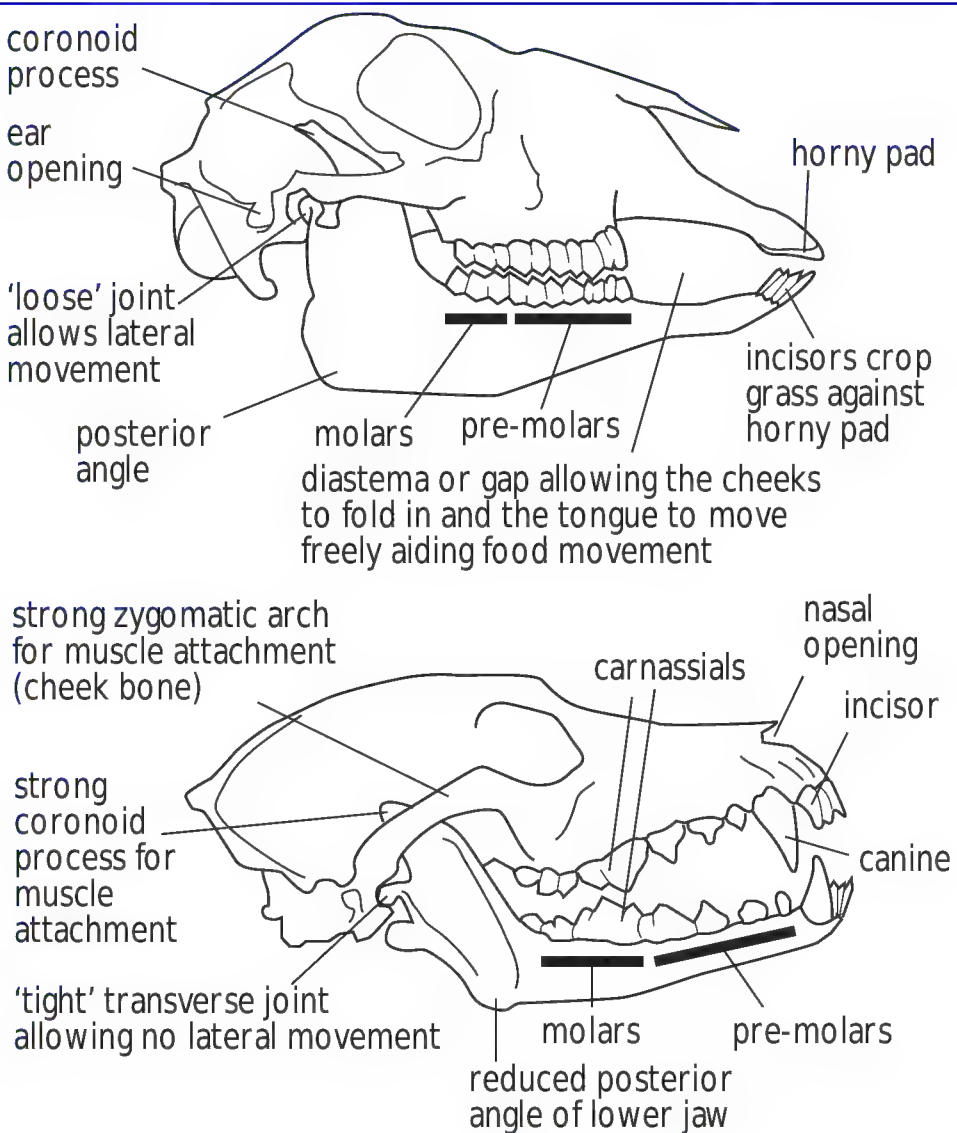


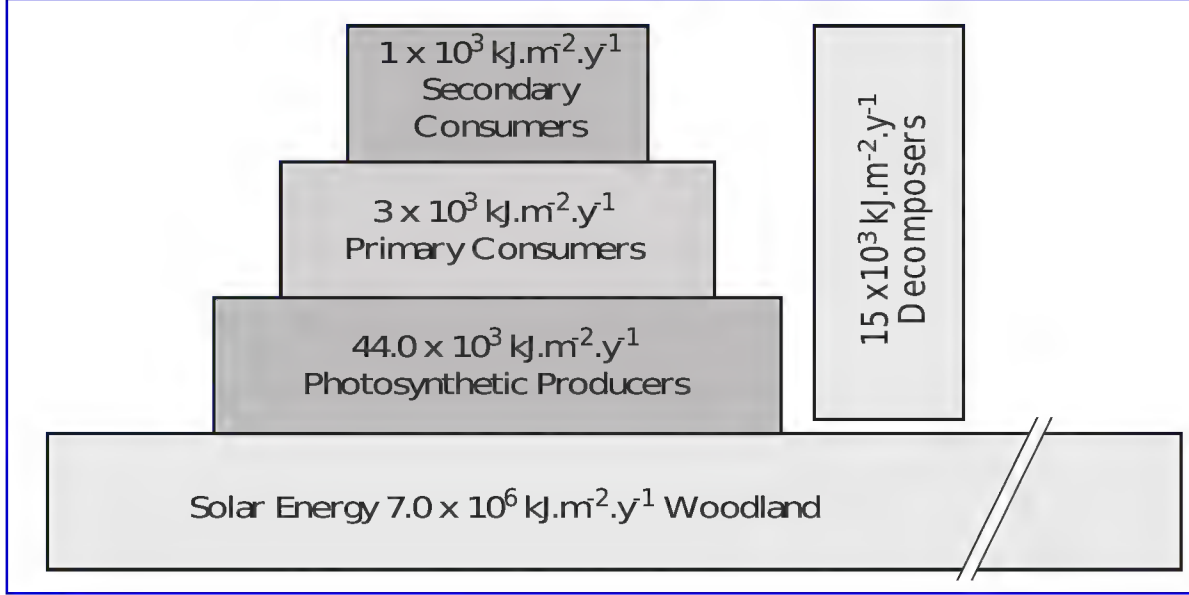


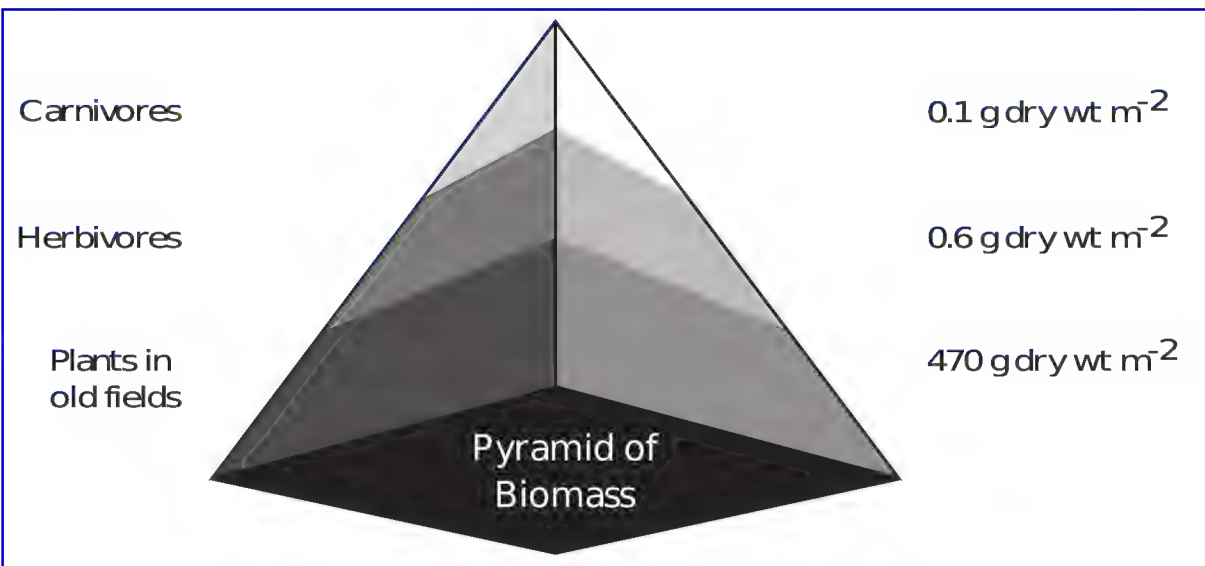


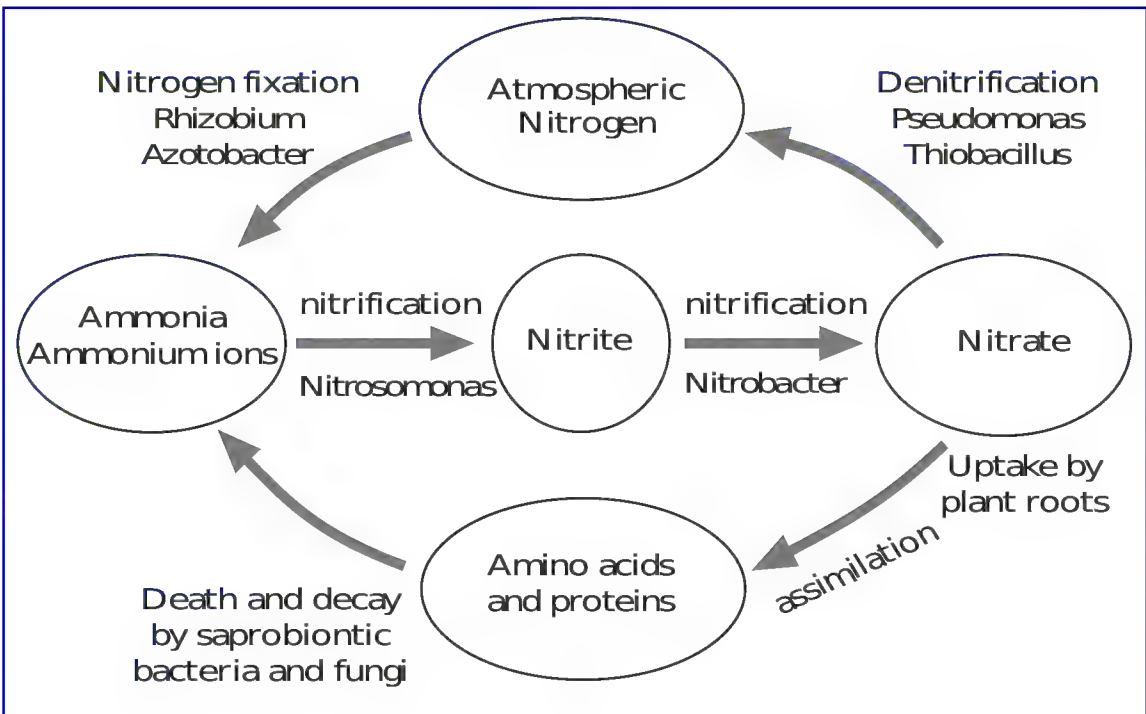
Growth Rates of Different Body Parts in Humans

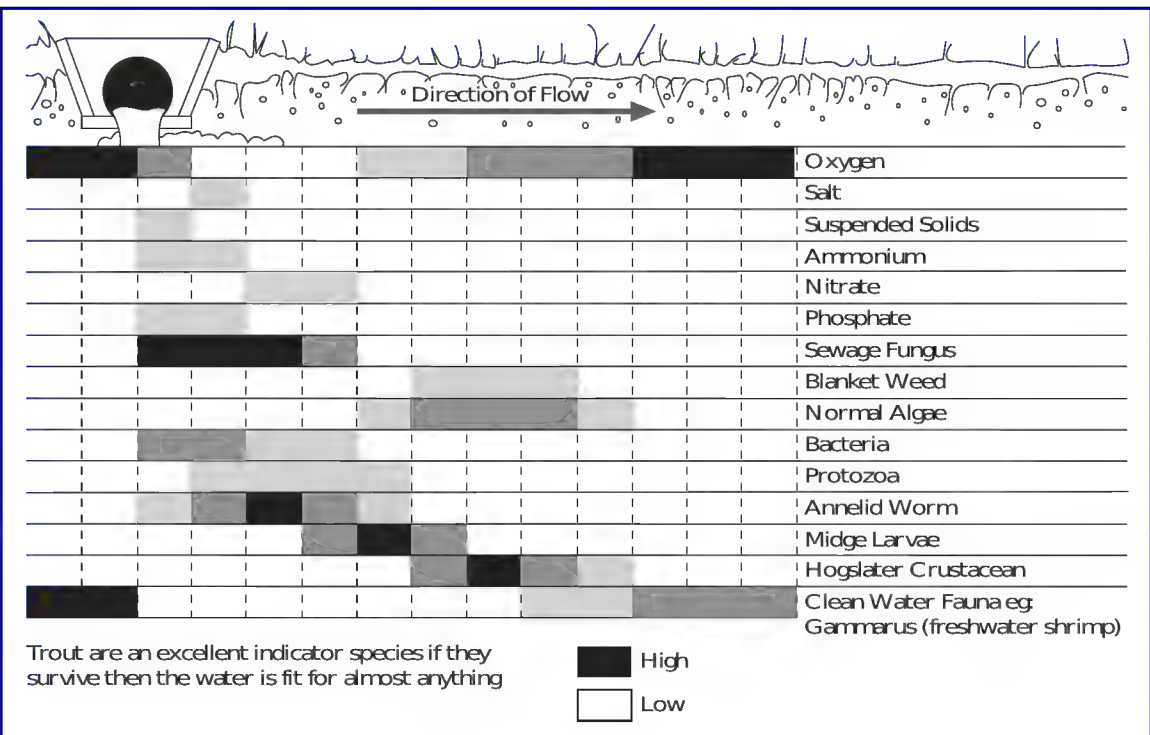












Biology or Biology (Human)



Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

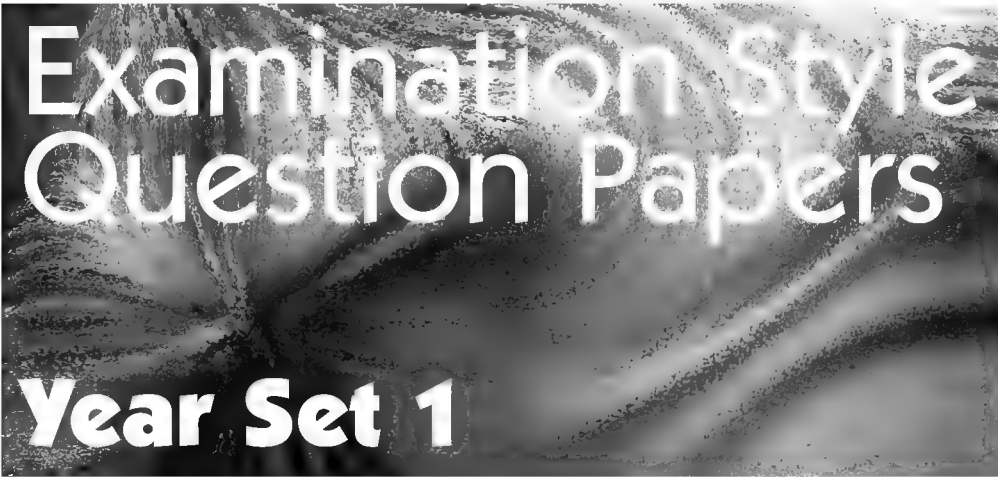
**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

Complete with Assessment Grids & Mark Schemes

FELTHAM PRESS

Biology or Biology (Human)



**Examination Style
Question Papers**

Year Set 1

Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

Complete with Assessment Grids & Mark Schemes

FELTHAM PRESS

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 1 - Molecules and cells

Year Set 1

Time allowed | hour 20 minutes

Instructions:

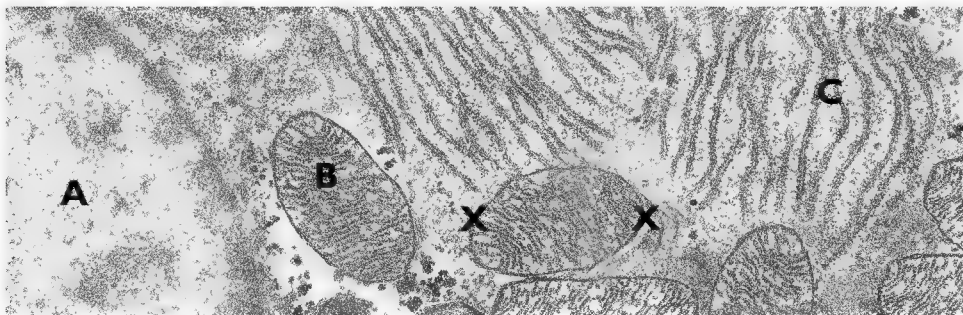
- Answer ALL NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- The maximum mark for this paper is 70.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question 1

The picture below shows part of an animal cell as seen under an electron microscope at a magnification of $\times 25\,000$, with all parts shown accurately to scale.



- a) Identify structures **A** to **C**.

A _____ (1)
 B _____ (1)
 A _____ (1)

- b) Describe two ways in which a bacterial cell differs from the cell shown above.

i) _____ (1)
 ii) _____ (1)

- c) Calculate the actual size of structure C as measured between the two points marked X. Show your workings.

 _____ (3)

Total 8

Question 2

Fick's law states that diffusion rate is proportional to:

surface area x difference in concentration / thickness of exchange surface

a) Explain how each of the factors in the equation affects the rate of diffusion.

i) Surface area.

(1)

ii) Difference in concentration.

(1)

iii) Thickness of exchange surface.

(1)

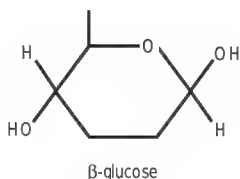
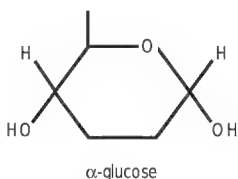
b) What feature of a mitochondrion increases its surface area for diffusion?

(1)

Total 4

Question 3

- a) The structure of alpha glucose and beta glucose is shown below:

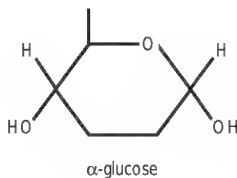
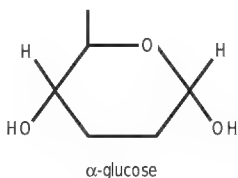


- i) The short-hand convention used in drawing organic molecules in this way omits the carbon atoms. Indicate on one of the diagrams above where the 6 carbon atoms of glucose are to be found. (1)

- ii) Describe how the two molecules shown differ in structure.

_____ (1)

- b) Two alpha glucose molecules are shown below.



- i) Indicate on the diagram how the disaccharide maltose would be formed. (1)

- ii) What type of reaction is this known as? (1)

- iii) Name the chemical bond formed in this way. (1)

Total 5

Question 4

- a) Give a definition of the term catalyst.

(1)

- b) Name an enzyme and the reaction that it catalyses.

(1)

- c) What is meant by the term 'enzyme specificity'.

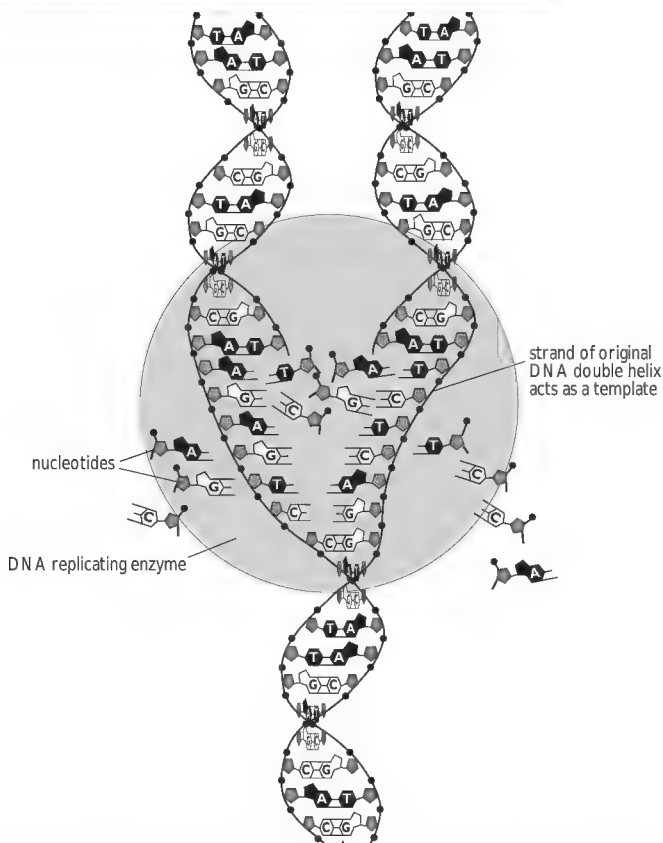
(1)

- d) Enzymes are denatured by extremes of pH. Explain what is meant by the term 'denatured'.

(2)

Total 5

Question 5



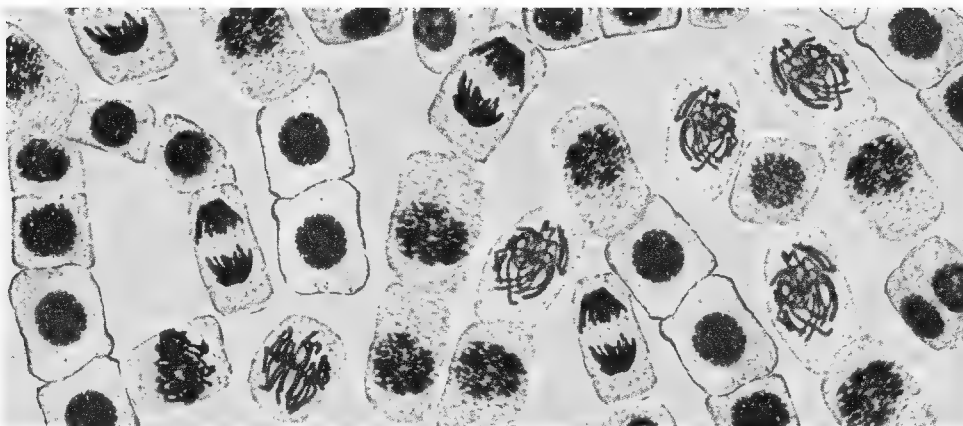
Study the diagram of replicating DNA shown above and answer the questions that follow.

- a) On the diagram:
- label the two new strands of DNA; (1)
 - mark with an 'X' a pair of complementary bases. (1)
 - indicate with an arrow the direction in which the new strands of DNA are being formed. (1)
- b) With reference to the diagram describe what is meant by semi-conservative replication;
- _____
- _____
- _____ (3)
- c) Name an enzyme involved in catalysing the chemical reactions of DNA replication
- _____ (1)

Total 7

Question 6

Study the illustration below of stained cells from a squashed plant root tip cells, showing various stages of mitosis, and then answer the questions that follow.



- a) i) Indicate with an X on the illustration a cell which is showing the separation of chromatids (1)
- ii) Indicate with a Y on the illustration a cell which is showing the chromosomes lining up on the equator of the nuclear spindle. (1)
- iii) Explain why plant root tips are a good source of cells undergoing mitosis.

(2)

Question continued...

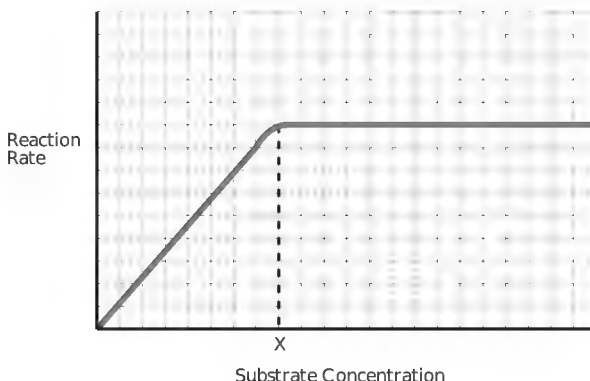
- b)** In the space below make an accurate drawing, enlarged x 1.5, of two cells showing different stages in mitosis.
Do not label your drawing.

(5)

Total 8

Question 7

The graph below shows the rate of an enzyme catalysed reaction (with the amount of enzyme fixed) plotted against increasing substrate concentration



- a) i) Explain what is meant by a rate limiting factor.

(2)

- ii) Identify the rate limiting factor up to point X on the graph.

(1)

- iii) Identify the rate limiting factor past point X on the graph.

(1)

- b) Describe what would happen to the rate of reaction if more enzyme was added at point X

(2)

- c) Explain the levelling off of the rate of reaction seen in the graph in terms of the formation of enzyme substrate complex.

(5)

Total 11

Question 8

The data below are from an experimental investigation on osmosis carried out by a student using cylinders of well washed beetroot tissue from which no pigment was leaking.

Immersed in	Initial mass (g)	Mass (g) after 30 minutes	% difference
distilled water	2.81	2.97	+5.70
0.3 M sucrose solution	2.79	2.89	+3.60
1.0 M sucrose solution	2.78	2.60	-6.10

Where M = molarity which is a measure of concentration.

- a) Explain the figures in the table in terms of osmosis for the cells immersed in each of the following.

- i) Distilled water.

(3)

- ii) 0.3 M sucrose solution.

(1)

- iii) 1.0 M sucrose solution.

(2)

- b) Explain the following results, observed after the cylinders of beetroot tissue from the above experiment were subjected to the following treatments.

- i) When placed in distilled water they all showed a gain in mass of around 5.7% compared to their original mass.

(1)

- ii) When gradually brought to the boil, red pigment flooded into the distilled water.

(2)

- c) One of the problems with experiments in which changes of mass of tissues are measured is that relatively large amounts of water are held in the cellulose cell wall. Explain why this gives an inaccurate picture of water movement by osmosis in experiments such as the one described.

(3)

Total 12

Question 9

Give an account of the structure, properties and functions of the cell surface membrane.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Total 10

Assessment Grid

Biology and Biology (Human)

Unit 1 - Molecules and cells

Year Set 1

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
1.1 Molecules			5							5
1.2 Enzymes				5	1		11			17
1.3 Cellular organisation	8	4			6			12	10	40
1.4 Cell cycle						8				8

Total 70

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	8	4	5	5	5	5	4	5	4	45
AO2										
Application/Analysis/Evaluation					2	3	7	7	6	25

Total 70

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 1 - Molecules and cells Year Set 1

Instructions

; = 1 mark / = alternative response

Question 1

The picture below shows part of an animal cell as seen under an electron microscope at a magnification of $\times 25\,000$, with all parts shown accurately to scale.

- a) Identify structures A to C.

A nucleus;

B mitochondrion;

C rough or granular endoplasmic reticulum;

(3)

- b) Describe two ways in which the structure of a bacterial cell differs from the cell shown above.

i) & ii) any two from

bacterium cell has no mitochondria;

no nucleus;

no endoplasmic reticulum;

(2)

- c) Calculate the actual size of structure C as measured between the two points marked X. Show your workings.

distance between points x-x = 25 mm;

magnification = $\times 25\,000$

therefore actual size = 25 divided by 25 000;

= 0.001 mm / 1.0 μm ;

(3)

Total 8

Question 2

Fick's law states that diffusion rate is proportional to:

surface area x difference in concentration / thickness of exchange surface

a) Explain how each of the factors in the equation affects the rate of diffusion:

i) surface area

the larger the surface area the faster the diffusion rate;

(1)

ii) difference in concentration

the larger the difference in concentration the faster the diffusion rate;

(1)

iii) thickness of exchange surface

the thicker the exchange surface the slower the diffusion rate/ vice versa;

(1)

b) What feature of a mitochondrion increases its surface area for diffusion?

the folding(s) of the internal membrane / cristae;

(1)

Total 4

Question 3

- a) The structure of alpha glucose and beta glucose is shown below:
- i) The short-hand convention used in drawing organic molecules in this way omits the carbon atoms. Indicate on one of the diagrams above where the 6 carbon atoms of glucose are to be found.
all 6 carbons accurately marked; (1)
 - ii) Describe how the two molecules shown differ in structure.
positions of OH and H groups on carbon one reversed; (1)
- b) Two alpha glucose molecules are shown below:
- i) Indicate on the diagram how the disaccharide maltose would be formed.
removal of elements of water correctly indicated; (1)
 - ii) Name the type of reaction that you have indicated on the diagram.
condensation reaction; (1)
 - iii) Name the chemical bond formed in this way.
glycosidic bond (1)

Total 5

Question 4

- a) Give a definition of the term catalyst.
a substance which speeds up the rate of a reaction;
without itself being used up;
both needed for the mark; (1)
- b) Name an enzyme and the reaction that it catalyses.
both needed for the mark; (1)
- c) What is meant by the term 'enzyme specificity'.
an enzyme will only catalyse a specific reaction or type of reaction; 1)
- d) Enzymes are denatured by extremes of pH. Explain what is meant by the term 'denatured'
rendered irreversibly inactive.
as a result of permanent disruption of their 3 D structure / active site; (2)

Total 5

Question 5

Study the diagram of replicating DNA shown below and answer the questions that follow.

- a) On the diagram:
- i) label the two new strands of DNA. (1)
 - ii) mark with an 'X' the position of a pair of complementary bases. (1)
 - iii) indicate with an arrow the direction in which the new strands of DNA are being formed. (1)
- b) With reference to the diagram describe what is meant by semi-conservative replication;
each daughter DNA double helix;
has conserved one strand of the original DNA double helix;
therefore half of daughter DNA double helix 'old' and half 'new'. (2)
- c) Name an enzyme involved in catalysing the chemical reactions of DNA replication
DNA polymerase (1)

Total 7

Question 6

Study the illustration below of stained cells from a squashed plant root tip, showing various stages of mitosis, and answer the following questions.

- a) i) Indicate with an 'X' on the illustration a cell which is showing the separation of chromatids. (1)
- ii) Indicate with an 'Y' on the illustration a cell which is showing the chromosomes lining up on the equator of the nuclear spindle. (1)
- iii) Explain why plant root tips are a good source of cells undergoing mitosis.
growing regions;
apical meristem just behind tip;
produce nuclei by mitosis in all directions; (2)
- b) In the space below make an accurate drawing, enlarged x 1.5, of two cells showing different stages in mitosis. Do not label your drawing.
correct size / magnification;
correct proportions;
correct number of cells
chromosomes accurately represented;
no shading; (4)

Total 8

Question 7

The graph below shows the rate of an enzyme catalysed reaction (with the amount of enzyme fixed) plotted against increasing substrate concentration

- a) i) Explain what is meant by a rate limiting factor.
that factor that is controlling / 'limiting' the rate of reaction at any given time;
any change in the factor results in a change in the rate of reaction; (2)
- ii) Identify the rate limiting factor up to point X on the graph.
substrate concentration; (1)
- iii) Identify the rate limiting factor past point X on the graph.
enzyme concentration; (1)
- b) Describe what would happen to the rate of reaction if more enzyme was added at point X.
rate would increase;
as substrate is limiting factor; (2)
- c) Explain the levelling off of the rate of reaction seen in the graph in terms of the formation of enzyme substrate complex.
enzyme forms enzyme substrate complex by combination with substrate;
at active site;
by 'lock and key' induced fit;
when saturated with substrate all enzymes immediately taken up in enzyme substrate complex;
rate of formation cannot be speeded up by addition of more substrate; (5)

Total 11

Question 8

The data below are from an experimental investigation on osmosis carried out by a student using cylinders of well washed beetroot tissue from which no pigment was leaking.

- a) Explain the figures in terms of osmosis in:
- i) distilled water,
cell contents have a lower water potential than distilled water;
as a result of dissolved solutes;
water enters through partially permeable cell surface membrane by osmosis; (3)
 - ii) 0.3 M sucrose solution,
the water potential gradient operates in the same direction but is less steep; (1)
 - iii) 1.0 M sucrose solution,
1.0 M sucrose solution has a lower water potential than the cell contents;
therefore water leaves the cell by osmosis; (2)
- b) Explain the results after the cylinders of beetroot tissue from the above experiment were then subjected to the following treatments.
- i) When placed in distilled water they all showed a gain in mass of around 5.7% compared to their original mass.
effects of osmosis reversible;
therefore showed gains similar to cylinder in distilled water originally; (1)
 - ii) When they are gradually brought to the boil, red pigment flooded into the distilled water.
membrane structure broken down by heat;
therefore becomes fully permeable to pigment which floods out; (2)
- c) One of the problems with experiments in which changes of mass of tissues are measured is that relatively large amounts of water are held in the cellulose cell wall. Explain why this gives an inaccurate picture of water movement by osmosis in experiments such as the one described.
cellulose cell wall completely permeable;
outside the cell surface membrane;
plays no part in osmosis but contributes to changes in mass; (3)

Total 12

Question 9

Give an account of the structure, properties and functions of the cell surface membrane.

- 1 'fatty' in nature, two layers of phospho-lipids bilayer);
- 2 hydrophobic poles together, hydrophilic poles 'outwards';
- 3 stabilised by cholesterol;
- 4 surface proteins / glycoproteins for recognition and communication;
- 6 glycolipids;
- 6 embedded proteins, some enzymes catalysing membrane reactions;
- 7 some carriers involved with active transport across the membrane;
- 8 some 'pore' proteins allowing passage of water soluble solutes;
- 9 the fluid mosaic model;
- 10 partially permeable selective barrier to the passage of materials into and out of cells;
- 12 maintains the integrity of the contents;
- 13 can be involved in movement e.g. pseudopodia in white cells;
- 14 endocytosis and exocytosis;

Total 10

Examination Style Question Papers Biology and Biology (Human)

Name: _____

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set I

Time allowed | hour 20 minutes

Instructions:

- Answer NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- You must answer Section 1 and
EITHER Section B: Biology
OR Section H: Biology (Human)
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- The maximum mark for this paper is 70.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

You must answer Section I and

EITHER Section B: Biology OR Section H: Biology (Human)

Section 1

Answer ALL FOUR questions in this section.

Question 1

The rate of diffusion across a surface is proportional to:

surface area x difference in concentration/thickness of exchange surface

By reference to the alveoli as surfaces involved in gas exchange, explain how each of the factors in the equation affects the rate of diffusion:

a) surface area

(2)

b) difference in concentration

(2)

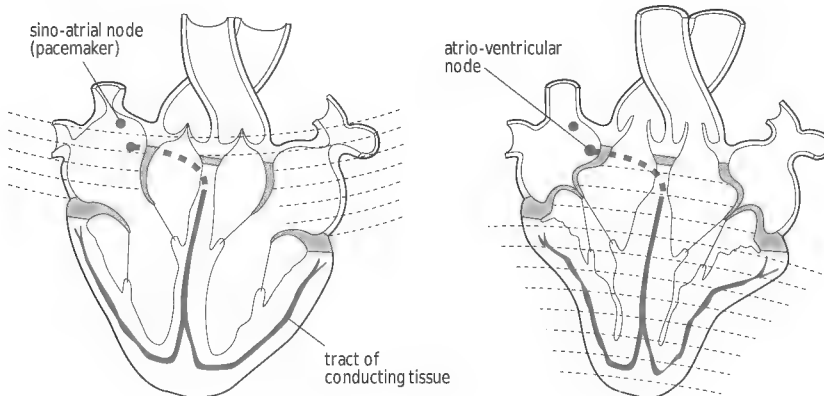
c) thickness of the exchange surface

(2)

Total 6

Question 2

The diagrams below show vertical sections of the heart at different stages of the cardiac cycle where the spread of electrical activity through the walls is indicated by the radiating curved lines.



- a) Draw arrows on the diagrams above to show the direction electrical activity spreads through the walls of the heart. (1)

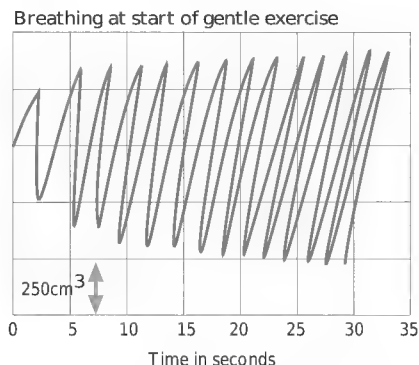
- b) Relate this pattern of spread of electrical activity, and the resultant contractions of the atria and ventricles in the cardiac cycle, to the direction of the blood flow through the heart. (3)

- c) Describe what causes the heart valves to open and close during the cardiac cycle. (2)

Total 6

Question 3

The diagram below is of a trace from a respirometer measuring the breathing of a person at rest who then starts exercising at a rate which causes them to start breathing more heavily and quickly.



- a) Ventilation of the lungs is by tidal flow in and out of a single air tube the trachea. What are the main disadvantages of this method of ventilating a respiratory system?

(2)

- b) Using the trace in the diagram above:

- i) Calculate the tidal volume at rest.

(1)

- ii) Calculate the breathing rate at rest.

(1)

- iii) Calculate the volume of air moved through the system per minute during exercise.

(3)

- c) State two changes in the blood which stimulate the increase in breathing rate during exercise. Where are the receptors located that respond to these changes in the blood.

(3)

Total 10

Question 4

The drawing below is of an X-ray of the stomach and first part of the duodenum after a barium meal (which shows up in X-rays).



a) Describe and explain the appearance in the drawing of:

i) the stomach,

(3)

ii) the first part of the duodenum,

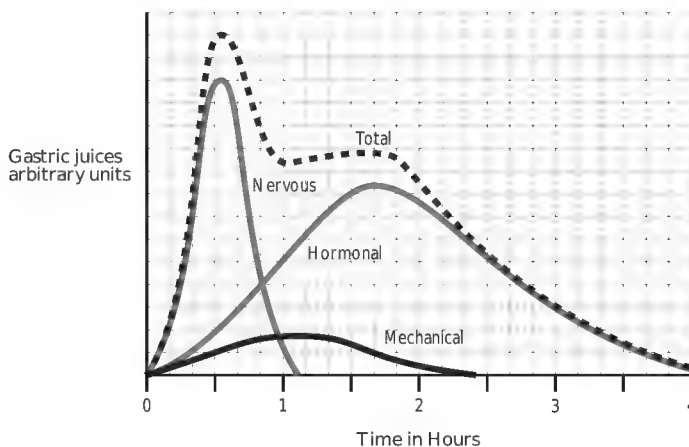
(3)

b) Brunner's glands are a distinctive feature of the first part of the duodenum. Describe their function.

(3)

Question continued...

- c) The graph below shows the phases of secretion of gastric juices after food enters the mouth.



- i) List the sequence in which the different stimuli have their major effect.

(1)

- ii) How long after food has entered the mouth does the total gastric secretion reach its peak?

(1)

- iii) Name the site of origin of the hormones which stimulate the secretion of gastric juices.

(1)

Total 12

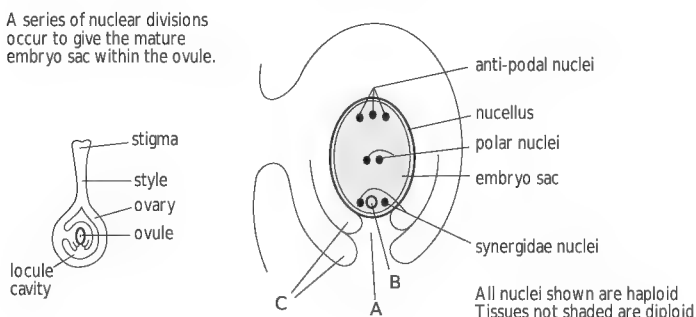
Section B : Biology

Answer ALL FIVE questions in this section.

Question B5

The diagrams below show the the main features of the ovule of a typical flowering plant.

A series of nuclear divisions occur to give the mature embryo sac within the ovule.



a) Match each of the following with the appropriate letter A, B, or C.

i) Ovum or egg nucleus

(1)

ii) Micropyle

(1)

b) Give brief definitions of the following.

i) Pollination.

(2)

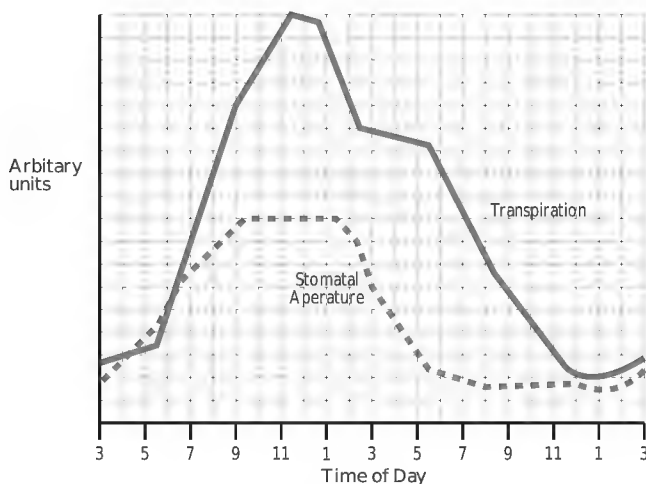
ii) Fertilisation

(2)

Total 6

Question B6

The graph below shows the relationship between the degree of opening of the stomata (stomatal aperture) and the rate of transpiration over a 24 hour period under natural conditions on a summer's day.



- a) i) Describe the general relationship between the stomatal aperture and the rate of transpiration.

(2)

- ii) Explain how the transpiration rate can rise and fall independent of the stomatal aperture.

(3)

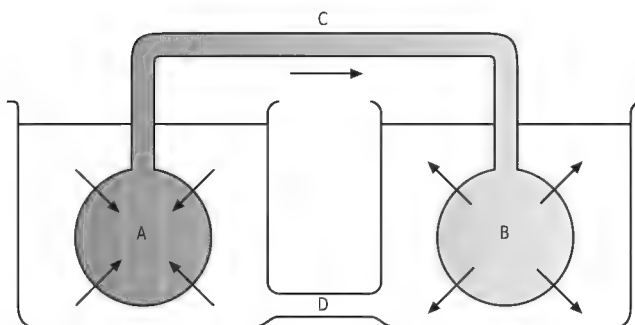
- (b) Some plants e.g. desert plants, close their stomata during the day and open them at night. Explain the advantage of this pattern of opening and closing to these plants.

(2)

Total 7

Question B7

The diagram below is of a simple model used to demonstrate the mass flow hypothesis for the translocation of sugars in the phloem.



a) Identify which part of the model represents:

i) the phloem;

(1)

ii) the xylem

(1)

b) For the movement of water and dissolved sugars to be maintained from chamber A to chamber B sugars must be continually added to A and removed from B. Identify the regions equivalent to A and B, and the processes that achieve these changes in the plant.

(5)

Total 7

Question B8

- a)** List two differences in structure between phloem tissue and xylem tissue that are relevant to their functions.

(2)

- (b)** State the function of the phloem.

(2)

- c)** If a length of stem of a living plant is killed by heating in a 'steam jacket' applied to that region, translocation stops but transpiration continues. Explain these observations with regard to the nature of phloem and xylem.

(2)

Total 6

Question B9

Give an account of the ways in which xerophytes are adapted to survive in conditions of water shortage.

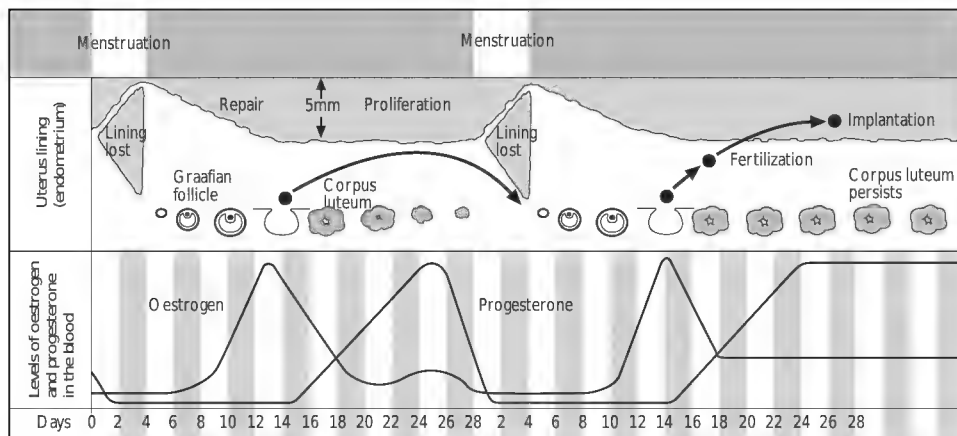
This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.**Total 10**

Section H : Biology (Human)

Answer ALL FIVE questions in this section.

Question H5

Study the diagram of the ovarian (menstrual) cycle in the human female and answer the following questions.



- a) i) What event in the ovary coincides with the peak in the level of oestrogen in the blood? (1)
- _____
- ii) What event results in the maintenance of high levels of progesterone in the blood beyond the normal time period? (1)
- _____
- (b) Give one function for each of the following:
- i) follicle stimulating hormone (1)
- _____
- ii) luteinising hormone (1)
- _____
- iii) oestrogen (1)
- _____
- iv) progesterone (1)
- _____

Total 6

Question H6

- a)** Explain the significance of reduction division (meiosis) on chromosome number in gamete formation .

(2)

- (b)** Explain the significance of chiasmata formation in the first division of reduction division (meiosis).

(2)

Total 4

Question H7

- a)** Give a definition of epithelial tissue.

(1)

- b)** Identify the type of epithelial tissue found in the following sites within the human body.

- i)** Bowman's capsules in the kidney

(1)

- ii)** Bile duct and renal tube

(1)

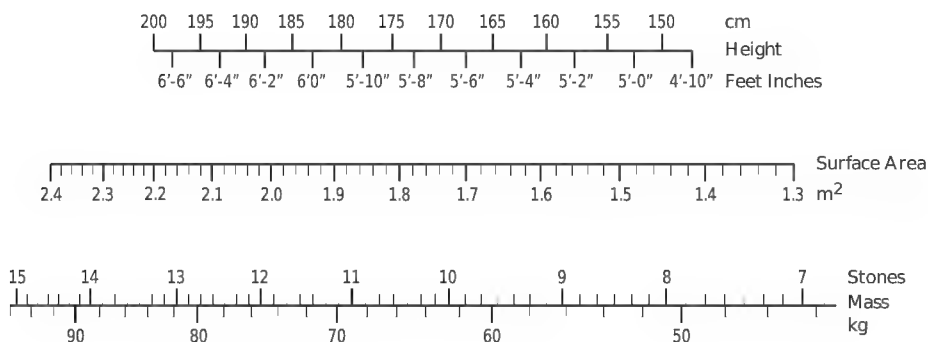
- iii)** Stomach and small intestine

(1)

Total 4

Question H8

The relationship between the size of an organism or structure, and the surface area to volume ratio is significant in the exchange of substances and heat. The nomogram below enables the surface area of an individual to be estimated from their height and weight.



a) Estimate the surface area of the two individuals:

i) X with a height of 195 cm and a weight of 71 kg,

_____ (1)

ii) Y with a height of 165 cm and a weight of 72kg.

_____ (1)

iii) Calculate the surface area to volume ratio of individuals X and Y.

 _____ (2)

Question continued...

(b) Making the oversimplified assumption that body mass is directly proportional to body volume, use the figures to:

- i)** describe which of the two individuals would have the higher heat **loss** (all other physiological factors being equal) when both were exposed to the same environmental conditions including an external temperature of 10°C with no special protective clothing.

(4)

- ii)** describe which of the two individuals would have the higher heat **production** under the same conditions as in (b) i).

(4)

Total 12

Question H9

Give an account of the the effects of reduced atmospheric pressure at high altitudes on the human body.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Total 10

Assessment Grid

Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set I

BIOLOGY

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
2B.1 Exchange & Environment	6		10	12						28
2B.2 Transport systems		6				7	7	6		26
2B.3 Adaptations & Environment									10	10
2B.4 Sexual reproduction					6					6
										Total 70

BIOLOGY

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	6	3	7	9	6	2	2	4	4	43
AO2										
Application/Analysis/Evaluation		3	3	3		5	5	2	6	27
										Total 70

HUMAN BIOLOGY

	Question Number									
Specification Section					5	6	7	8	9	Total
2H.1 Exchanges & Environment							4			4
2H.2 Transport of materials										
2H.3 Human ecology								12	10	22
2H.4 Human reproduction					6	4				10
										Total 36

HUMAN BIOLOGY

	Question Number									
Assessment Objective					5	6	7	8	9	Total
AO1										
Knowledge with Understanding					6		4	4		14
AO2										
Application/Analysis/Evaluation						4		8	10	22
										Total 36

Mark Schemes for Question Paper Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set I

Instructions

; = 1 mark / = alternative response

Section 1

Answer ALL FOUR questions in this section.

Question 1

The rate of diffusion across a surface is proportional to:

surface area $\times$ difference in concentration / thickness of exchange surface

- a) By reference to the alveoli as surfaces involved in gas exchange explain how each of the factors in the equation affects the rate of diffusion:

i) surface area

alveoli have a large surface area exposed to air and blood in the capillaries;

the larger the surface area the faster the diffusion rate;

(2)

ii) difference in concentration

blood flowing in the pulmonary capillaries and air moving in and out of the alveoli maintain the difference in concentration of oxygen and carbon dioxide;

the larger the difference in concentration the faster the diffusion rate;

(2)

iii) thickness of the exchange surface

the distance between the air and the red blood cells is small;

the thinner the exchange surface the faster the diffusion rate;

(2)

Total 6

Question 2

The diagrams below show vertical sections of the heart at different stages of the cardiac cycle where the spread of electrical activity through the walls is indicated by the radiating curved lines.

- a) Draw arrows on the diagrams above show the direction in which electrical activity spreads through the walls of the heart.
arrows radiating downwards and across in atria and upwards in ventricles;
possibly downwards in septum; (1)
- (b) Relate this pattern of spread of electrical activity, and the resultant contractions of the atria and ventricles in the cardiac cycle, to the direction of the blood flow through the heart.
arrow radiating downwards in atria results in downward contraction of atria;
forcing blood downwards into the ventricles;
arrow radiating upwards in ventricles results in upward contraction of ventricles;
forcing blood upwards into pulmonary arteries and main aorta; (3)
- c) Describe what causes the heart valves to open and close during the cardiac cycle.
heart valves are passive structures incapable of initiating movement;
pressure of blood forces valves open or shut;
dependent upon their one-way arrangement; (2)

Total 6

Question 3

The diagram below is of a trace from a respirometer measuring the breathing of a person at rest, who then starts exercising at a rate which causes them to start breathing more heavily and quickly.

- a) Ventilation of the lungs is by tidal flow in and out of a single air tube the trachea. What are the main disadvantages of this method of ventilating a respiratory system?

stationary air close to the respiratory surface;

diffusion gradients of respiratory gases decrease;

(2)

- b) Using the trace in the diagram above.

- ii) Calculate the tidal volume at rest from the trace in the diagram above.

500 cm³

(1)

- iii) Calculate the breathing rate at rest.

24 complete breaths per minute;

(1)

- iv) Calculate the volume of air moved through the system per minute during exercise.

tidal volume = $3.5 \times 250 = 875 \text{ cm}^3$;

3 breaths per 5 seconds = 2625 cm^3

$\times 12$ for one minute = 31.5 dm^3 per minute;

(3)

- b) State two changes in the blood which stimulate the increase in breathing rate during exercise. Where are the receptors that respond to these changes in the blood.

increase in carbon dioxide;

decrease in pH / increase in acidity;

carotid bodies and the respiratory control centres in the brain;

(3)

Total 10

Question 4

The drawing below is of an X-ray of the stomach and first part of the duodenum after a barium meal (which shows up in X-rays).

- a) Describe and explain the appearance in the drawing of:
- i) the stomach,
opaque barium meal shows up black;
clear area at top;
air and gastric secretions;
the 'J' shape demonstrates the 'hopper and mill' functions;
pyloric sphincter / constriction marks end of stomach / entry to duodenum; (3)
 - ii) the first part of the duodenum,
small amounts of food chyle) entering from the stomach;
via the pyloric sphincter muscle;
constricted and expanded regions indicate;
peristaltic / wave-like contractions of circular and longitudinal muscle in wall;
moving the 'bolus' along the duodenum; (3)
- b) Brunner's glands are a distinctive feature of the first part of the duodenum. Describe their function.
secrete alkaline juice rich in mucus;
for correct pH for action of pancreatic enzymes;
alkaline salts neutralise stomach acid;
mucus protects mucosa of the first part of the duodenum;
against damage by acid chyme from stomach; (3)
- c) The graph below shows the phases of secretion of gastric juices after food enters the mouth.
- i) List the sequence in which the different stimuli have their major effect.
nervous, mechanical, hormonal (1)
 - ii) How long after food has entered the mouth does the total gastric secretion reach its peak?
about 30 minutes; (1)
 - iii) Name the site of origin of the hormones which stimulate the secretion of gastric juices.
stomach wall; (1)

Total 12

Section B : Biology

Answer ALL FIVE questions in this section.

Question B5

The diagrams show the the main features of the ovule of a typical flowering plant.

a) Match each of the following with the appropriate letter A, B, or C.

i) Ovum or egg nucleus = B

(1)

ii) Micropyle = A

(1)

b) Give brief definitions of the following.

i) Pollination.

transfer of pollen from the pollen sac of the stamen;
to the stigma of the carpel;

(2)

ii) Fertilisation

the fusion of two gametic nuclei;
to produce a fertilised egg or zygote;

(2)

Total 6

Question B6

The graph below shows the relationship between the degree of opening of the stomata (stomatal aperture) and the rate of transpiration over a 24 hour period under natural conditions on a summer's day.

- a) i) Describe the general relationship between the stomatal aperture and the rate of transpiration.
as one rises so does the other;
with their highest values around midday;
and their lowest values in the dark; (2)
- ii) Explain how the transpiration rate can rise and fall independent of the stomatal aperture.
once stomata opened maximally no longer limiting factor;
rise and fall of transpiration affected by environmental factors which become limiting;
change in temperature / change in humidity / change in air movements; (3)
- b) Some plants e.g. desert plants, close their stomata during the day and open them at night.
Explain the advantage of this pattern of opening and closing to these plants.
in hot dry conditions danger of excess water loss by transpiration;
via stomata therefore shut during day therefore must open at night for carbon dioxide uptake. (2)

Total 7

Question B7

The diagram below is of a simple model used to demonstrate the mass flow hypothesis for the of the translocation of sugars in the phloem.

a) Identify which part of the model represents:

i) the phloem;

C;

(1)

ii) the xylem;

D;

(1)

b) For the movement of water and dissolved sugars to be maintained from chamber A to chamber B sugars must be continually added to A and removed from B. Identify the regions equivalent to A and B, and the processes that achieve these changes in the plant.

chamber A = leaves;

carrying out photosynthesis;

at a rate in excess of respiration in the light;

chamber B = roots;

carrying out respiration on the products of the excess of photosynthesis over respiration in the leaves;

(5)

Total 7

Question B8

- a) List two differences in structure between phloem tissue and xylem tissue that are relevant to their functions.

Phloem	Xylem	
cytoplasmic contents	empty cell lumen;	
cellulose cell walls	lignified cell walls;	
sieve plates	no end walls in vessels;	(2)

- b) State the function of the phloem.

transport / translocation of organic substances;
from 'sources' to 'sinks' (2)

- c) If a length of stem in a living plant is killed by heating in a 'steam jacket' applied to that region, translocation stops but transpiration continues. Explain these observations with regard to the nature of phloem and xylem.

phloem must be living for translocation to occur;
xylem is a dead tissue unaffected by heat; (2)

Total 6

Question B9

Give an account of the ways in which xerophytes are adapted to survive in conditions of water shortage.

modifications to increase water uptake;
decrease water loss by transpiration;
water uptake increased by extensive root systems;
transpiration decreased by stomatal modifications e.g.;
reduction in number;
none on top surface;
sunken in grooves and pits;
covered with 'hairs';
open stomata at night and close in day;
with corresponding change in photosynthesis;
leaf surface area reduced to needles or spines;
leaf fall in dry periods;
leaf folding and rolling in dry periods;
thick waxy cuticle on leaves;

Total 10

Section H: Biology (Human)

Answer ALL FIVE questions in this section.

Question H5

Study the diagram of the ovarian (menstrual) cycle in the human female and answer the following questions.

- a) i) What event in the ovary coincides with the peak in the level of oestrogen in the blood?
ovulation (1)
- ii) What event results in the maintenance of high levels of progesterone in the blood beyond the normal time period?
fertilisation (1)
- b) Give one function for each of the following:
- i) luteinising hormone.
stimulate ovulation / leads to development of corpus luteum; (1)
- ii) follicle stimulating hormone
stimulates development and growth of ovarian follicles / stimulates ovary to secrete oestrogen; (1)
- iii) oestrogen
stimulates development of secondary sexual characteristics / growth of the uterus lining; (1)
- iv) progesterone
stimulates development of lining of uterus in second half of cycle / maintains placenta; (1)

Total 6

Question H6

- a) Explain the significance of reduction division (meiosis) on chromosome number in gamete formation .
division of a diploid nucleus with two sets of chromosomes;
to give haploid daughter nuclei with one set of chromosomes;
to re-establish diploid number after fertilisation; (2)
- b) Explain the significance of chiasmata formation in the first division of reduction division (meiosis).
genetic recombination (crossing over) of maternal and paternal chromosomal material;
increases genetic variation in gametes; (2)

Total 4

Question H7

- a) Give a definition of epithelial tissue.
lines internal and external surfaces; (1)
- b) Identify the types of epithelial tissue found in the following sites within the human body.
- i) Bowmans capsule of kidney
Squamous epithelium, (1)
- ii) Bile duct and renal tube
Cuboidal epithelium, (1)
- iii) Stomach and small intestine
Columnar epithelium, (1)

Total 4

Question H8

The relationship between the size of an organism or structure and the surface area to volume ratio is significant in the exchange of substances and heat. The nomogram below enables the surface area of an individual to be estimated from their height and weight.

a) Estimate the surface area of the two individuals:

i) X with a height of 190 cm and a weight of 74 kg,

X - 2.02 m^2 ;

(1)

ii) Y with a height of 165 cm and a weight of 72kg.

Y - 1.8 m^2 ;

(1)

iii) Calculate the surface area to volume ratio of individuals X and Y.

X has $\text{SA}/\text{V} = 0.273$;

Y has $\text{SA}/\text{V} = 0.25$;

(2)

b) Making the oversimplified assumption that body mass is directly proportional to body volume, use the figures to:

i) describe which of the two individuals would have the higher heat **loss** (all other physiological factors being equal) when both were exposed to the same environmental conditions including an external temperature of 10°C with no special protective clothing.

heat lost by the body which is at 37°C ;

X with the greater surface area will lose more heat than Y;

(2)

ii) describe which of the two individuals would have the higher heat **production** under the same conditions as in b) i).

heat generated by the metabolism of the volume of the body;

therefore surface area to volume ratio important;

X has largest $\text{SA}/\text{V} = 0.273$;

therefore X will have the higher heat production rate;

as the body compensates for the heat loss;

(4)

Total 12

Question H9

Give an account of the the effects of reduced atmospheric pressure at high altitudes on the human body.

'thinning' of air / less dense;

reduced lung volumes;

hyperventilation;

excess removal of carbon dioxide / respiratory alkalosis;

kidneys excrete hydrogencarbonate;

blood loses buffering capacity;

decrease in plasma volume;

increase red blood cell fraction / haematocrit;

cardiac output increases;

percentage oxygen the same as at sea level but lower partial pressure;

conditions of oxygen shortage / hypoxia;

breathlessness / reduced aerobic capacity

secretion of erythropoietin (EPO) stimulated;

increased red blood cell production by red bone marrow;

Total 10

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 3 - Energy and the Environment

Year Set I

Time allowed | hour

Instructions:

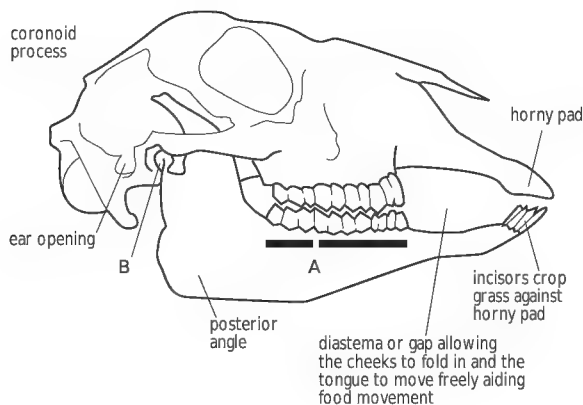
- Answer ALL THREE questions in the spaces provided.

Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 38
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question I

The diagram below shows a skull of a sheep which is a ruminant herbivore.



- b)** Describe the problems presented by vegetation as a food source for herbivores.

(2)

- b)** For each of the labelled structures A and B briefly explain how they are adapted to a herbivorous diet.

A (1)

B (1)

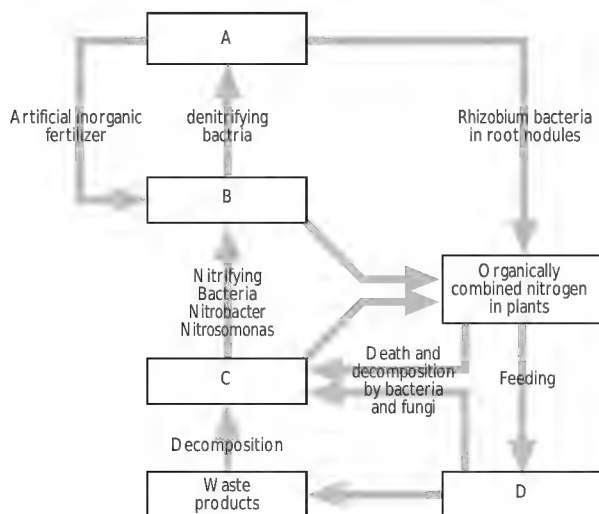
- c)** Describe another adaptation to a herbivorous diet in ruminants apart from the modifications of the skull.

(2)

Total 6

Question 2

The flow chart below is a simple representation of the Nitrogen Cycle.



- a) Match the letters in the blank boxes with the most appropriate of the following:

Nitrates, Ammonium salts, Nitrogen in air, Animals

A _____ (1)

B _____ (1)

C _____ (1)

- b) i) Name a saprobiontic organism;

_____ (1)

- ii) The amount of naturally fixed nitrogen in a fertile soil can be supplemented by the addition of nitrate containing fertilisers. However, under average conditions only about 50% will be utilised by plants with much being washed (leached) out by rainfall into rivers and eventually lakes or oceans. Nitrates which reach natural underground reservoirs of fresh water aquifers) represent a health hazard.

Examine the diagram of the nitrogen cycle and name which organisms could be used in water purification works to remove these nitrates, and explain how they would achieve the removal of nitrates from water supplies.

_____ (3)

Question continued...

c) Explain why there is so much nitrogen containing substance:

i) in the faeces of herbivorous animals,

(2)

ii) the urine of animals.

(3)

Total 12

Question 3

Study the passages and the diagram and answer the following questions.

- a)** The laws of thermodynamics determine the one way flow of energy. The first law states, that energy cannot be created or destroyed, although it may be transformed from one type, e.g. light, into another, e.g. potential energy of food.

Name the process by which energy is transformed from light into the potential energy of food, and give a named example of an organism that carries out this transformation.

(1)

- b)** The second law of thermodynamics states that no process involving an energy transformation can occur unless there is a degradation of energy from a concentrated form into a dispersed form, with some always being dispersed into unavailable heat energy. Thus no transformation, e.g. light to food, can be 100% efficient. The second law of thermodynamics is also known as the law of entropy, entropy being a measure of disorder in terms of the amount of unavailable heat energy in a closed thermodynamic system.

Explain whether 'unavailable heat energy' has any role in an ecosystem.

(2)

- c)** Organisms and ecosystems maintain their highly ordered low entropy disorder state by transforming energy from high to low utility states in a controlled manner.

Explain this statement with reference to the principle of the food chain.

(1)

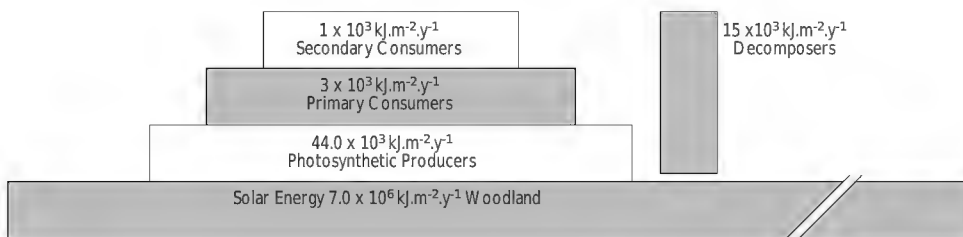
- d)** The interaction of energy and materials in an ecosystem is of primary concern to ecologists. In fact the one-way flow of energy and the circulation of materials are the two great principles of general ecology. (Odum)

Two major substances are recycled in all ecosystems. For each one give the name of the element being recycled and then describe in what form each substance is being taken up from, and being released into, the environment.

(2)

Question continued...

A pyramid of energy



- (e) i) Calculate the percentage efficiency of transfer of energy between the photosynthetic producers and the primary consumers.

(1)

- ii) Describe the specific ways in which energy is lost between the the primary and secondary consumers.

(3)

Question continued...

Ecosystems Classified According to Source and Level of Energy (Odum)	Annual Energy Flow kJ.m^{-2}
Unsubsidised Natural Solar-powered Ecosystems e.g. open oceans, upland forests	4200 - 42 000
Naturally subsidised Solar-powered Ecosystems e.g. tidal estuaries.	42 000 - 168 000
Man subsidised Solar-powered Ecosystems e.g. agriculture	42 000 - 168 000

In addition to energy from the sun a coastal estuary receives an input of energy from tides, waves and currents, which contribute to the work of recycling mineral nutrients and transporting food in from other ecosystems.

"In a very real sense organisms in the estuary are adapted to utilise tidal power." (Odum)

- f) i)** Identify the ecosystem in the table which has the widest range of figures representing annual energy flow through ecosystems and explain why your choice has the widest range of annual energy flow.

(1)

- ii)** Explain how agriculture is a Man subsidised Solar-powered Ecosystem.

(5)

- g)** In the light of your answer to (f) (ii) explain why the figures for an estuary are the same as those for agriculture.

(1)

- h)** Explain why claims that livestock increase in mass by as much as 50% when fed on concentrated dry feed are misleading when compared to the efficiency of conversions in natural ecosystems.

(2)

Total 20

Assessment Grid

Biology and Biology (Human)

Unit 3 - Energy and the Environment

Year Set I

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
3.1 Modes of nutrition	6									6
3.2 Ecosystems										
3.3 Energy flow										
3.4 Recycling of nutrients		12								12
3.5 Energy resources			20							20
3.6 Human influences										
										Total 38

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	0	0	Total
AO1										
Knowledge with Understanding	4	4	7							15
AO2										
Application/Analysis/Evaluation	2	8	13							23
										Total 38

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 3 - Energy and the Environment Year Set I

Instructions

; = 1 mark / = alternative response

Question I

The diagram below shows a skull of a sheep which is a ruminant herbivore.

- a) Describe the problems presented by vegetation as a food source for herbivores.
relatively low in nutrients therefore large volumes must be processed;
cellulose cell walls (with silica in grasses) tough barrier to extraction; (2)
- b) For each of the labelled structures A and B briefly explain how they are adapted to a herbivorous diet.
- B - loose jaw articulation allows side to side grinding movements of cheek teeth; (1)
A - battery of ridged molars and premolars for grinding vegetation; (1)
- c) Describe another adaptation to a herbivorous diet in ruminants apart from the modifications of the skull.
modifications of the gut for 'rumination' / chewing the cud;
elaboration of the oesophagus and stomach for mutualistic fermenting microorganisms; (2)

Total 6

Question 2

The flow chart below is a simple representation of the Nitrogen Cycle.

- a) Match the letters in the blank boxes with the most appropriate of the following:

Nitrates, Ammonium salts, Nitrogen in the air, Animals

A - Nitrogen in the air

(1)

B - Nitrates

(1)

C - Ammonium salts

(1)

- b) i) Name a saprobiontic organism;

Rhizopus;

(1)

- ii) The amount of naturally fixed nitrogen in a fertile soil can be supplemented by the addition of nitrate containing fertilisers. However, under average conditions only about 50% will be utilised by plants with much being washed (leached) out by rainfall into rivers and eventually lakes or oceans. Nitrates which reach natural underground reservoirs of fresh water aquifers) represent a health hazard.

Examine the diagram of the nitrogen cycle and name which organisms could be used in water purification works to remove these nitrates, and explain how they would achieve the removal of nitrates from water supplies.

denitrifying bacteria;

under anaerobic conditions use nitrates as final oxygen acceptor in respiration

liberating nitrogen gas;

(3)

- c) i) Explain why there is so much nitrogen containing substance:

in the faeces of herbivorous animals,

inefficiencies of digestion of plant material;

nitrogen containing substances in microorganisms from gut;

(2)

- ii) the urine of animals.

animals cannot store excess protein / amino acids;

therefore excess in diet and also from general turnover of proteins in metabolism;

metabolised to nitrogen containing waste products e.g. urea;

(3)

Total 12

Question 3

Study the passages and the diagrams and answer the following questions.

The laws of thermodynamics determine the one way flow of energy. The first law states, that energy cannot be created or destroyed, although it may be transformed from one type, e.g. light, into another, e.g. potential energy of food.

- a) Name the process by which energy is transformed from light into the potential energy of food, and give a named example of an organism that carries out this transformation.

photosynthesis;

any green plant;

(1)

The second law of thermodynamics states that no process involving an energy transformation can occur unless there is a degradation of energy from a concentrated form into a dispersed form, with some always being dispersed into unavailable heat energy. Thus no transformation, e.g. light to food, can be 100% efficient. The second law of thermodynamics is also known as the law of entropy, entropy being a measure of disorder in terms of the amount of unavailable heat energy in a closed thermodynamic system.

- b) Explain whether 'unavailable heat energy' has any role in an ecosystem.

by raising temperature of organisms provides optimum conditions for enzyme activity;

by sharing lost heat animals can reduce heat gradients with environment;

therefore conserving body heat;

(2)

Organisms and ecosystems maintain their highly ordered low entropy disorder state by transforming energy from high to low utility states in a controlled manner.

- c) Explain this statement with reference to the principle of the food chain.

a series of feeding of trophic levels / energy transfers between organisms each capable of best exploiting that trophic level;

(1)

The interaction of energy and materials in an ecosystem is of primary concern to ecologists. In fact the one-way flow of energy and the circulation of materials are the two great principles of general ecology. (Odum)

- d) Two major substances are recycled in all ecosystems. For each one give the name of the element being recycled and then describe in what form each substance is being taken up from, and being released into, the environment.

carbon as carbon dioxide;

nitrogen as ammonium ions;

(2)

- (e) i) Calculate the percentage efficiency of transfer of energy between the photosynthetic producers and the primary consumers.

$$3/44 \times 100 = 6.8 \%$$

(1)

Question continued...

- ii) Describe the specific ways in which energy is lost between the primary and secondary consumers.

inefficiencies of digestion and absorption;

energy lost as heat in reactions of liver and muscle contraction;

energy lost in excretory products;

(3)

Ecosystems Classified According to Source and Level of Energy (Odum)	Annual Energy Flow kJ.m^{-2}
Unsubsidised Natural Solar-powered Ecosystems e.g. open oceans, upland forests	4200 - 42 000
Naturally subsidised Solar-powered Ecosystems e.g. tidal estuaries.	42 000 - 168 000
Man subsidised Solar-powered Ecosystems e.g. agriculture	42 000 - 168 000

In addition to energy from the sun a coastal estuary receives an input of energy from tides, waves and currents, which contribute to the work of recycling mineral nutrients and transporting food in from other ecosystems.

"In a very real sense organisms in the estuary are adapted to utilise tidal power." (Odum)

- (f) i) Identify the ecosystem in the table which has the widest range of figures representing annual energy flow through various ecosystems and explain why your choice has the widest range of annual energy flow.

Unsubsidised Natural Solar-powered Ecosystems $\times 10$;

estimates only / impossible to measure accurately;

differences in energy flows in terrestrial and aquatic ecosystems;

(2)

- ii) Explain how agriculture is a Man-subsidised Solar-powered Ecosystem.

inorganic fertilisers require energy for their production;

imported organic fertilisers require energy for their transport;

the incorporation of fertilisers into the soil requires energy;

cultivation of the soil ie turnover and mixing requires energy;

control of pests with pesticides requires energy;

(5)

- (g) In the light of your answer to (f) (ii) explain why the figures for an estuary are the same as those for agriculture.

tidal power equivalent to input of energy into agriculture by man;

(1)

- (h) Explain why claims that livestock increase in mass as much as 50% when fed on concentrated dry feed are misleading when compared to efficiency of conversions in natural ecosystems.

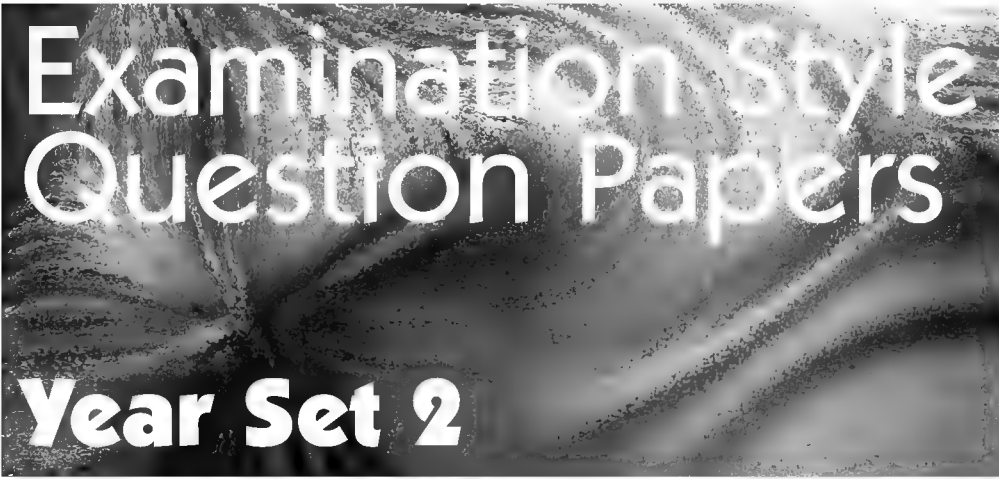
food being dry weight concentrate is being compared with;

wet weight of livestock;

(2)

Total 20

Biology or Biology (Human)



**Examination Style
Question Papers**

Year Set 2

Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

Complete with Assessment Grids & Mark Schemes

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Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 1 - Molecules and cells

Year Set 2

Time allowed | hour 20 minutes

Instructions:

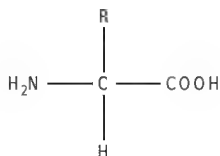
- Answer ALL NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- The maximum mark for this paper is 70.
- This type of paper would carry 33.3 per cent of the total marks for AS level.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question 1

The structural formula of an amino acid is shown below.

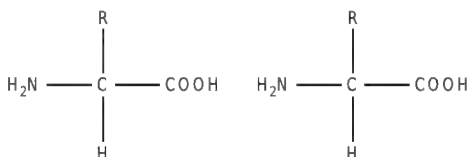


- a) There are about 20 different types of amino acid to be found in proteins from living organisms, explain how the structural formula shown above applies to them all even though they are different.

(2)

- b) On the diagram below show how two amino acids can combine.

(2)



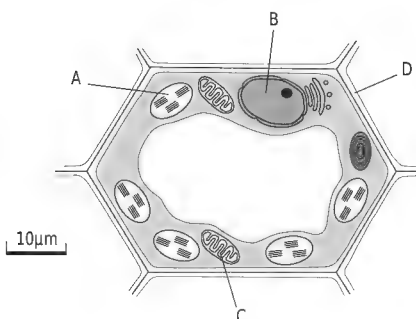
- c) Name the type of bond formed by the combination of two amino acids.

(1)

Total 5

Question 2

Study the diagram of a generalised plant cell as seen under the electron microscope and answer the questions that follow.



a) Identify structures **A** to **D**

- A _____ (1)
B _____ (1)
C _____ (1)
D _____ (1)

b) Name a structure in the diagram which would not be visible under even the best light microscope.

_____ (1)

Total 5

Question 3

- a) Explain what is meant by the following terms, with regard to the uptake of substances by cells:

- i) facilitated diffusion

(2)

- ii) active transport

(3)

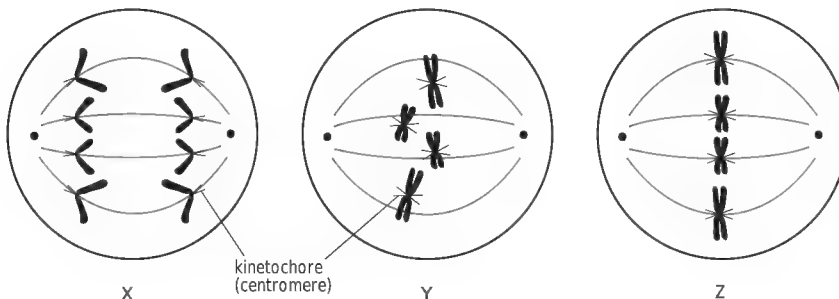
- b) Explain why, when respiration is inhibited in cells bathed in pure water, substances, especially ions, are released from the cells.

(3)

Total 8

Question 4

Study the diagrams below of different stages in mitosis and answer the following questions.



- a) Write the letters in the correct order to match the sequence in which these stages occur in mitosis.

(1)

- b) Describe what is occurring with respect to the chromosomes / chromatids in each of the stages shown in diagrams Y and Z.

(4)

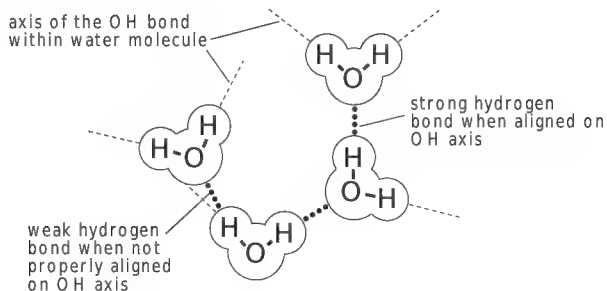
- c) Explain the shape of the chromosomes in diagram X.

(3)

Total 8

Question 5

The diagram shows a representation of the 'dipolar nature' of water.



a) Explain how the 'dipolar nature' of water accounts for the following characteristics of water.

i) The high latent heat of vaporization.

(2)

ii) Surface tension.

(1)

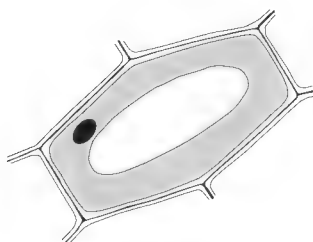
b) Describe the importance to living organisms of the fact that water has its highest density at 4°C.

(1)

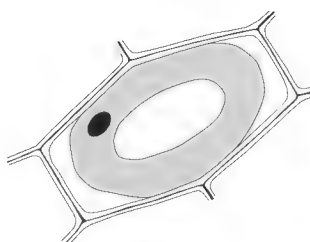
Total 4

Question 6

The diagrams below show two plant cells, each bathed in a different external solution.



Cell A



Cell B

- a) i) Identify the cell which is in a solution more dilute than the cell contents.

(1)

- ii) Describe the appearance of the cell which is in a solution more concentrated than the cell contents.

(2)

Question continued...

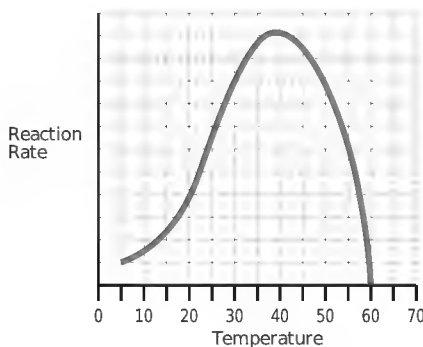
- b)** In the space below make an accurate drawing, enlarged $\times 1.5$, of the two cells. Do not label your drawing.

(5)

Total 8

Question 7

The graph shows the effect of changing temperature on the rate of an enzyme controlled reaction.



- a) i) Identify the optimum temperature for this enzyme.

(1)

- ii) Identify the temperature at which the enzyme is completely denatured.

(1)

- b) i) Explain why the rate of reaction slows at temperatures below the optimum.

(3)

- ii) Explain why the rate of reaction slows at temperatures above the optimum..

(2)

- c) A graph of rate of enzyme reaction against pH would have a similar shape as the one above, but there is an important difference between the state of the enzyme at the lowest temperature and the state of the enzyme at the lowest pH. Explain what this difference is.

(3)

Total 10

Question 8

- a) The genetic code consists of a sequence of bases on a strand of DNA, and can be represented by a series of letters on a line as shown below

T A C C G T T C T A C C

- i) Describe what the letters represent, and give their names.

(2)

- ii) Draw a similar line with letters to represent the complementary strand of DNA.

(1)

- iii) Draw a similar line with letters to represent the complementary strand of mRNA to the original DNA strand shown at the start of the question.

(1)

- b) The table below shows the genetic code on a strand of mRNA for selected amino acids.

Amino acid	mRNA codons
alanine	GCA, GCC, GCG, GCU
arginine	AGA, AGG, CGA, CGC, CGG, CGU
tryptophan	UGG
lysine	AAA, AAG
methionine	AUG (also acts as the 'start' codon so that every polypeptide chain initially starts with methionine)

Using the information in the table give answers to the following.

- i) Write out the sequence of amino acids coded for by the original strand of DNA shown above in part (a) of the question.

(2)

- ii) Explain what is meant by describing the genetic code as 'degenerate'.

(2)

- iii) Explain what is meant by describing the genetic code as 'non-overlapping'.

(4)

Total 12

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

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Assessment Grid Biology and Biology (Human)

Unit 1 - Molecules and cells

Year Set 2

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
1.1 Molecules	5				4				10	19
1.2 Enzymes							10			10
1.3 Cellular organisation			8			8		12		28
1.4 Cell Cycle		5		8						13
										Total 70

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	5	5	8	5	4	6	3	4	4	44
AO2										
Application/Analysis/Evaluation				3		2	7	8	6	26
										Total 70

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 1 - Molecules and cells

Year Set 2

Instructions

; = 1 mark / = alternative response

Question 1

The structural formula of an amino acid is shown below.

- a) There are about 20 different types of amino acid to be found in proteins from living organisms, explain how the structural formula shown above applies to them all even though they are different.

the R group varies in structure;

providing the variation between them;

(2)

- b) On the diagram below show how two amino acids can combine.

showing removal of elements of water;

formation of CO-NH bond;

(2)

- c) Name the type of bond formed by the combination of two amino acids.

peptide bond;

(1)

Total 5

Question 2

a) Identify structures A to D

A = Chloroplast

B = Nucleus

C = Mitochondrion

D = Cell wall

(4)

b) Name a structure in the diagram which would not be visible under even the best light microscope.

ribosome

(1)

Total 5

Question 3

a) Explain what is meant by the following terms, with regard to the uptake of substances by cells:

i) facilitated diffusion

diffusion down a diffusion gradient;

from higher concentration to lower concentration;

speeded up/ made easier by the presence of special carriers in the membrane;

(2)

ii) active transport

uptake against the prevailing diffusion gradient;

from lower concentration to higher concentration;

involving carriers in cell membrane;

using energy from respiration / ATP;

(3)

b) Explain why, when respiration is inhibited in cells bathed in pure water, substances, especially ions, are released from the cells.

in pure water the diffusion gradient is from the more concentrated cell contents to the pure water;

this situation is maintained by active ion uptake;

using energy from respiration / ATP;

if respiration is inhibited active uptake is reduced and substances diffuse out of the cell into the surrounding water;

if respiration inhibited completely, membrane breaks down and all cell contents are released into the surrounding water;

(3)

Total 8

Question 4

Study the diagrams below of different stages in mitosis and answer the following questions.

- a) Write the letters in the correct order to match the sequence in which these stages occur in mitosis.

Y, Z, X

(1)

- b) Describe what is occurring with respect to the chromosomes / chromatids in each of the stages shown in diagrams Y and Z.

Y - the chromosomes (each of two chromatids) are just formed;

and moving towards the equator of the nuclear spindle apparatus;

Z - the chromosomes (each of two chromatids) are arranged on the equator;

by means of the kinetochore centromere) attached to fibres of the spindle apparatus;

(4)

- c) Explain the shape of the chromosomes in diagram X.

the kinetochores centromeres) are the centres of movement of the chromosomes;

they lead the way along the spindle fibres towards the centrioles at the poles of the spindle;

the 'arms' of the chromosomes trail behind;

(3)

Total 8

Question 5

The diagram shows a representation of the 'dipolar nature' of water.

a) Explain how the 'dipolar nature' of water accounts for the following characteristics of water :

i) the high latent heat of vaporization.

H bonds between the opposite charged 'poles';

hold water molecules together;

so much energy is needed to separate them for vaporisation;

(2)

ii) surface tension

electrostatic attraction between the opposite charged 'poles' hold water molecules together which at the surface results in the formation of a surface tension;

(1)

b) Describe the importance to living organisms of the fact that water has its highest density at 4°C.

ice floats allowing life to survive beneath it;

(1)

Total 4

Question 6

The diagrams below show two plant cells, each bathed in a different external solution.

- a) i) Identify the cell which is in a solution more dilute than the cell contents.
cell A; (1)
- ii) Describe the appearance of the cell which is in a solution more concentrated than the cell contents.
the cell membrane is withdrawn from the cell wall;
the central vacuole is smaller than in cell A; (2)
- b) In the space below make an accurate drawing, enlarged $\times 1.5$, of the cells. Do not label your drawing.
correct size / magnification;
correct proportions;
correct number of cells
cell wall thickness appropriate;
accurate detail of cell contents; (5)

Total 8

Question 7

The graph shows the effect of changing temperature on the rate of an enzyme controlled reaction.

- a) i) identify the optimum temperature for this enzyme.

37°C; (1)

- ii) Identify the temperature at which this enzyme is completely denatured.

60°C (1)

- b) i) Explain why the rate of reaction slows at temperatures below the optimum.

rate of collisions of reacting molecules temperature dependent;

the lower the temperature the lower the rate of collisions;

lowers the rate of all chemical reactions including enzyme catalysed; (3)

- ii) Explain why the rate of reaction slows at temperatures above the optimum.

enzyme molecules progressively denatured / disrupted;

cannot form enzyme substrate complexes;

rate of reaction slows despite increased rate of collision; (2)

- c) A graph of rate of enzyme reaction against pH would have a similar shape as the one above, but there is an important difference between the state of the enzyme at the lowest temperature and the state of the enzyme at the lowest pH. Explain what this difference is.

at lowest temperature enzyme not denatured;

reversible;

at lowest pH enzyme denatured;

irreversible; (3)

Total 10

Question 8

- a) The genetic code consists of a sequence of bases on a strand of DNA, and can be represented by a series of letters on a line as shown below

T A C C G T T C T A C C

- i) Describe what the letters represent, and give their names.

nitrogenous bases;

thymine, adenine, guanine, and cytosine;

(2)

- ii) Draw a similar line with letters to represent the complementary strand of DNA.

A T G G C A A G A T G G

(1)

- iii) Draw a similar line with letters to represent the complementary strand of mRNA to the original DNA strand shown at the start of the question.

A U G G C A A G A U G G

(1)

- b) The table below shows the genetic code on a strand of mRNA for selected amino acids.

Amino acid	mRNA codons
alanine	GCA, GCC, GCG, GCU
arginine	AGA, AGG, CGA, CGC, CGG, CGU
tryptophan	UGG
lysine	AAA, AAG
methionine	AUG (also acts as the 'start' codon so that every polypeptide chain initially starts with methionine)

Using the information in the table answer the following:

- i) write out the sequence of amino acids coded for by the original strand of DNA shown above in part (a) of the question

methionine-alanine-arginine-tryptophan;

(2)

- ii) explain what is meant by describing the genetic code as 'degenerate';

most amino acids are coded for by more than one triplet codon;

changes in the triplet codons (mutations) do not necessarily result in a change of the amino acid coded for;

(2)

- iii) explain what is meant by describing the genetic code as 'non-overlapping';

gene always starts from AUG;

determines bases in each subsequent triplet codon;

until 'stop' codon;

cannot 'overlap' by having bases contribute to more than one codon;

therefore a specific length of DNA (a gene) always codes for the same polypeptide;

(4)

Total 12

Question 9

Give an account of the structure and functions of fibrous and globular proteins as illustrated by collagen and insulin.

both composed of long chains of amino acids joined by peptide bonds;

polypeptide chains - their primary structure;

shaping of final structure as a result of formation of bonds between parts of chains;

ionic, hydrogen and disulphide bonds;

giving secondary, tertiary, and quaternary structures;

two broad groupings - fibrous which are structural and metabolically inert e.g. collagen;

collagen tough fibrous protein forms major structural protein of the body;

found in tendons, bone, areolar connective tissue (membranes);

three polypeptide chains held together by hydrogen bonds;

a triple helix;

and globular which are metabolically active e.g. hormone insulin;

two polypeptide chains held together by disulphide bonds;

Total 10

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set 2

Time allowed 1 hour 20 minutes

Instructions:

- Answer NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- You must answer Section 1 and
EITHER Section B: Biology
OR Section H: Biology (Human)
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

You must answer Section I and

EITHER Section B: Biology OR Section H: Biology (Human)

Section 1

Answer ALL FOUR questions in this section.

Question I

Air that is breathed in (inspired air) contains about 21% by volume of oxygen, and 0.04% by volume of carbon dioxide, and air that is breathed out (expired air) contains about 16% by volume of oxygen

- a) i) Name two other main components of inspired air.

(2)

- ii) Give figures for the percentage by volume of carbon dioxide in expired air.

(1)

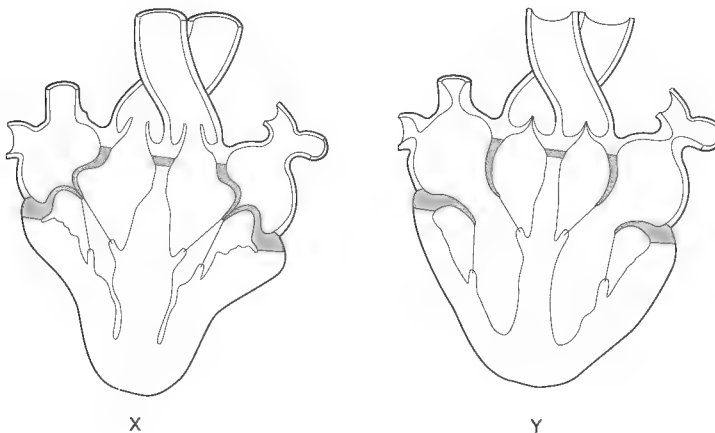
- b) Explain the relationship between the figures for inspired air, and the figures for expired air

(2)

Total 5

Question 2

Study the diagrams below showing the state of the heart at two stages in the cardiac cycle, and answer the questions that follow.



- a) Identify the diagram in which the ventricles are relaxed.

(1)

- b) Describe what causes the pocket valves to shut at the stage of the cardiac cycle shown in diagram Y.

(3)

- c) Explain how the tricuspid and bicuspid valves between the atria and the ventricles are prevented from opening in the wrong direction.

(3)

Total 7

Question 3

Study the following table relating to the composition of human faeces and answer the following questions.

Water	65.0 %
Solid material	35.0 %
of which bacteria	7.5 %
of 100 g Cellulose ingested	100 g lost in faeces
of 100 g fat ingested	6.0 g lost in faeces
mineral ions	
epithelial cells	
bile pigments	

- a) i) Comment on the significance of the figures for the ingestion and egestion (loss) of cellulose.

(2)

- ii) Comment on the efficiency of the digestion and absorption of fats.

(1)

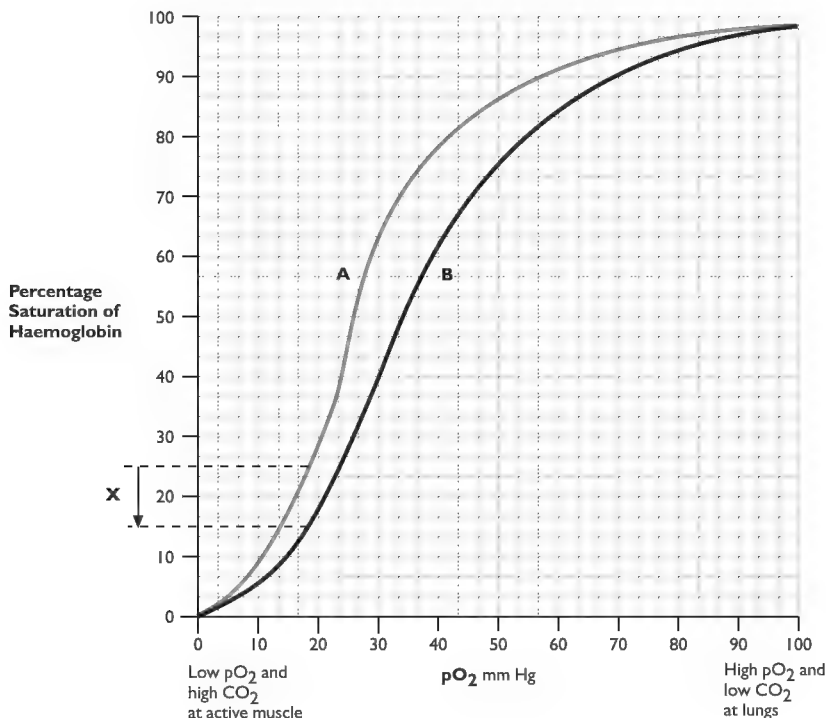
- b) Explain the high percentage of bacteria in the faeces.

(4)

Total 7

Question 4

Study the graph below showing the association of haemoglobin with oxygen at different partial pressures of oxygen, and answer the following questions.



- a) i) The two curves represent the percentage saturation of haemoglobin with oxygen at two different carbon dioxide concentrations, identify the curve on the diagram which is at the higher carbon dioxide concentration.

(1)

- ii) What effect would an increase in temperature and a decrease in pH have on the position of these curves, and what would this represent in terms of the association of oxygen with haemoglobin.

(2)

Question continued...

- iii)** With reference to the vertical arrow labelled X explain the significance of the differences between the two curves in respect to the delivery of oxygen to the tissues.

(3)

- b)** Explain how the difference between the two conditions of the two curves could be increased by the activity of the body.

(3)

- c)** Explain the physiological significance of the relative affinity (combining tendency) of:

- i)** adult haemoglobin and fetal haemoglobin,

(3)

- ii)** adult haemoglobin and myoglobin

(3)

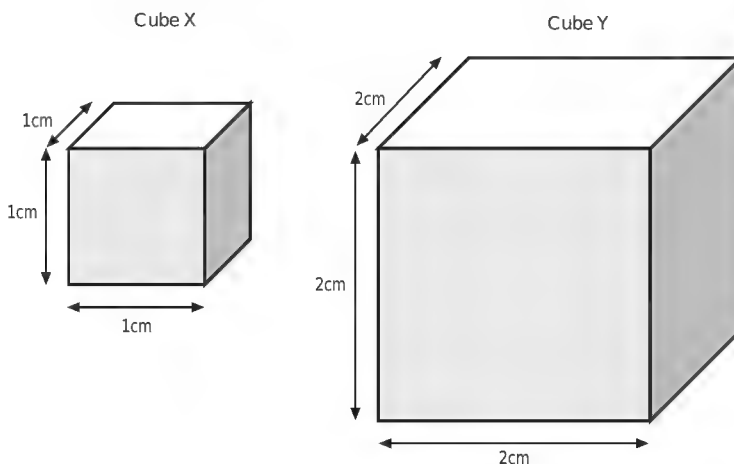
Total 15

Section B : Biology

Answer ALL FIVE questions in this section.

Question B5

The diagram shows two cubes and their dimensions in centimetres.



- a) Calculate the surface area to volume ratio for each of the two cubes shown above.

(2)

- b) i) Explain the significance of the surface area to volume ratio in relation to the exchange of substances and heat between organisms and their environment.

(4)

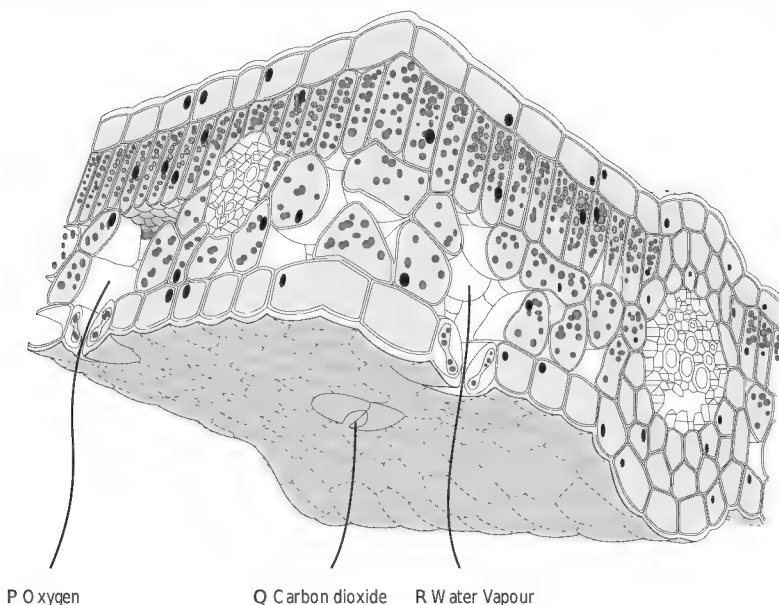
- ii) Name a structure in the typical flowering plant which is specialised to present a large surface area for exchanges.

(1)

Total 7

Question B6

The diagram below is of a section through a typical leaf of a flowering plant (a mesophyte).



- a) i) Place arrow heads on the lines P, Q, and R on the diagram passing through the stomata to show the overall direction of the diffusion of oxygen, carbon dioxide, and water respectively, at noon in conditions of average humidity

(3)

- ii) Give the name of a cell from which water is actually evaporating prior to diffusing out of the leaf.

(1)

- iii) Name the tissue in which most of the carbon dioxide that enters the leaf will be used.

(1)

- b) With decreasing diameter of the stomata the passage of water vapour is restricted more than that of carbon dioxide. Explain the advantage of this to the plant in terms of gaseous exchanges with the environment.

(3)

Total 8

Question B7

a) Describe the effect on transpiration of plants living:

i) completely submerged in water;

(1)

ii) rooted in mud at the bottom of water with floating leaves.

(1)

b) Describe and explain the effect of both these modes of life on the degree of development of the xylem tissue.

(2)

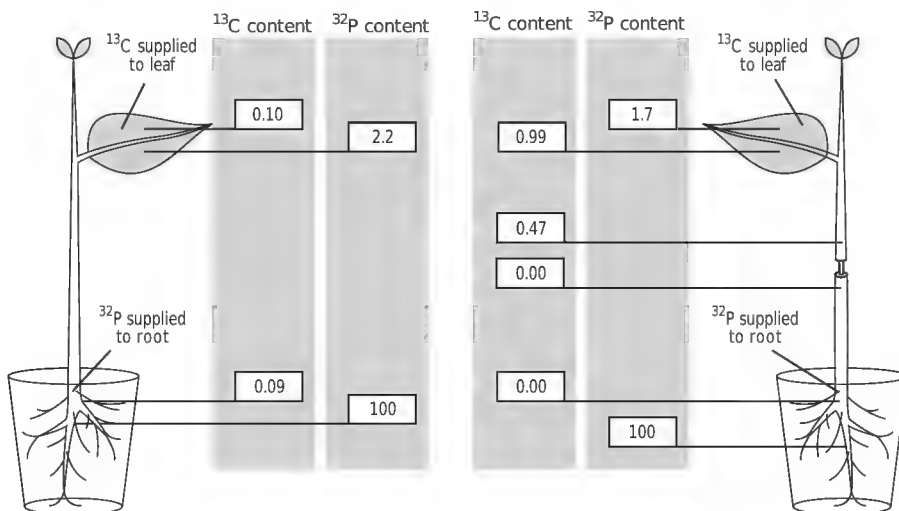
c) One characteristic of many plants such as those above (hydrophytes) is the presence of large air spaces, especially in submerged parts. Explain the function of these.

(2)

Total 6

Question B8

The diagrams below represent the results of ringing experiments on plants, leaves of which were exposed to radioactive ^{13}C labelled carbon dioxide and roots of which were exposed to radioactive ^{32}P labelled phosphate ions.



- a) By reference to the diagrams explain how this experiment demonstrates the role of phloem in the translocation of sugars.

(3)

- b) Studies with radioactive tracers have indicated rates of flow of sugars in the phloem of 1 metre per hour in grasses, and as high as 50 metres per hour in soya plants. Explain how this could be used as evidence against the mass flow hypothesis of translocation of sugars in the phloem.

(2)

Total 5

Section H : Biology (Human)

Answer ALL FIVE questions in this section.

Question H5

- a) Explain the dangers of inhaling carbon monoxide.

(3)

- b) i) Explain how the unborn child of a non-smoking woman can become poisoned by carbon monoxide, nicotine and cancer causing chemicals from tobacco smoke.

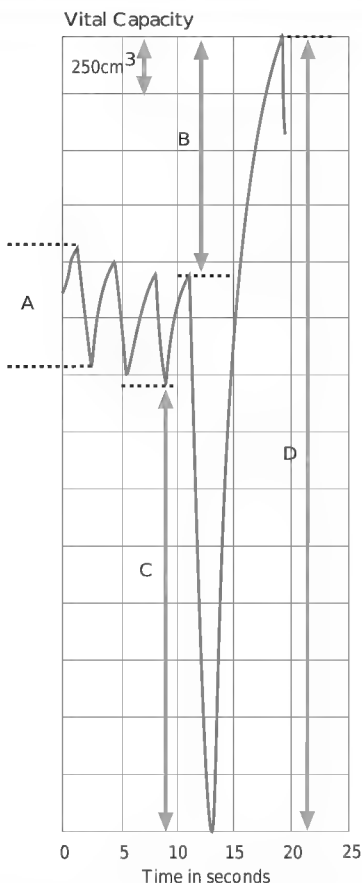
(2)

- ii) Explain the effect of tobacco smoking on the blood vessels and relate this to the lower birth weight of babies born to mothers who smoke.

(2)

Total 7

Question H6



The diagram above is of a trace from a spirometer measuring a person's breathing.

a) Use the letters on the diagram to identify the following:

i) tidal volume, _____ (1)

ii) inspiratory and expiratory reserve volumes, _____ (1)

iii) vital capacity _____ (1)

b) Explain why the tidal volume can never equal the vital capacity.

 _____ (2)

Total 5

Question H7

The human placenta is of the type where there is extensive breakdown of both maternal and fetal tissues so that in some areas the maternal and fetal circulations are only separated by the thickness of a capillary wall.

- a)** Explain the advantages of this arrangement.

(2)

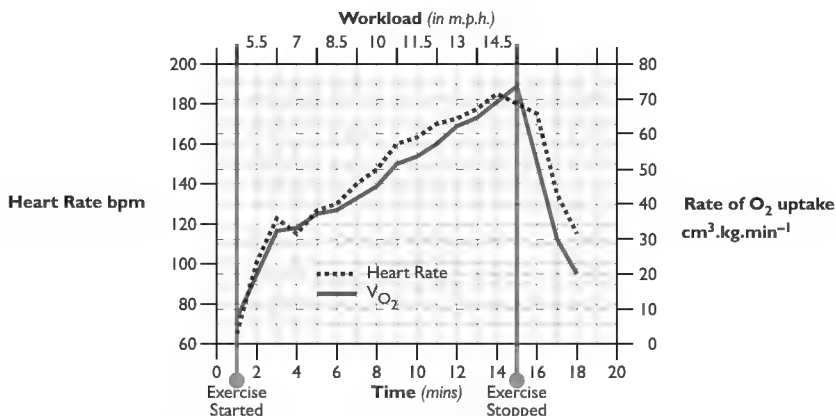
- b)** Explain the disadvantages of this arrangement.

(2)

Total 4

Question H8

Study the graph showing the heart rate and oxygen uptake of a middle distance runner performing a maximal treadmill test, and answer the following questions.



a) Identify the periods over which:

i) the greatest increase in rate of heart rate and oxygen uptake occurs;

(1)

ii) the oxygen uptake continues to increase and the heart rate decreases.

(1)

b) For the individual above identify the

i) resting heart rate;

(1)

ii) maximum heart rate.

(1)

c) Explain why the curves do not return to normal immediately after exercise stops.

(3)

d) Explain why the heart rate and oxygen uptake follow each other so closely throughout this investigation.

(3)

Total 10

Question H9

Give an account of the effects of ageing on the skeletal system.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

Total 10

Assessment Grid Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction
Year Set 2

BIOLOGY

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
2B.1 Exchanges & Environment	5		7		7	8			10	37
2B.2 Transport systems		7		15			6	5		33
2B.3 Adaptations & Environment										
2B.4 Sexual reproduction										

Total 70

BIOLOGY

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	5	7	4	6	3	5	4	5	6	45
AO2										
Application/Analysis/Evaluation			3	9	4	3	2		4	25

Total 70

HUMAN BIOLOGY

	Question Number									
Specification Section					5	6	7	8	9	Total
2H.1 Exchanges & Environment					7	5				12
2H.2 Transport of materials								10		10
2H.3 Human ecology										
2H.4 Human reproduction							4		10	14

Total 36

HUMAN BIOLOGY

	Question Number									
Assessment Objective					5	6	7	8	9	Total
AO1										
Knowledge with Understanding					3	3	4	4	1	15
AO2										
Application/Analysis/Evaluation					4	2		6	6	18

Total 33

Mark Schemes for Question Paper Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set 2

Instructions

; = 1 mark / = alternative response

Section 1

Answer ALL FOUR questions in this section.

Question 1

Air that is breathed in (inspired air) contains about 21% by volume of oxygen, and 0.04% by volume of carbon dioxide, and air that is breathed out (expired air) contains about 16% by volume of oxygen

- a) i) Name two other main components of inspired air.

nitrogen;

water vapour;

(2)

- ii) Give figures for the percentage by volume of carbon dioxide in expired air.

4 - 5%;

(1)

- b) Explain the relationship between the figures for inspired air, and the figures for expired air
the volume of carbon dioxide breathed out has been generated by oxidation;
of substrates by the roughly the same volume of oxygen;

(2)

Total 5

Question 2

Study the diagrams below showing the state of the heart at two stages in the cardiac cycle, and answer the following questions.

Diagrams of heart at ventricular diastole (Y) and systole (X)

- a) Identify the diagram in which the ventricles are relaxed.
diagram Y; (1)
- b) Describe what causes the pocket valves to close at the stage of the cardiac cycle shown in diagram Y.
by blood falling back down the blood vessels exiting the right and left ventricles aorta and pulmonary arteries);
as a result of the lower pressure in the empty ventricles;
blood fills 'pockets';
'pockets' block and shut the blood vessels; (3)
- c) Explain how the tricuspid and bicuspid valves between the atria and the ventricles are prevented from opening in the wrong direction.
tendons / cords attached to lower surface of valves and to walls of ventricles;
when ventricles contract, upward force of blood forces valves up;
prevented from opening the wrong way by tendon cords becoming taut;
aided by muscles of ventricular wall exerting a downward pull on tendon cords; (3)

Total 7

Question 3

Study the following table relating to the composition of human faeces and answer the following questions.

Water 65.0 %
Solid material 35.0 %
of which bacteria 7.5 %
of 100 g Cellulose ingested 100.0 g lost in faeces
of 100 g fat ingested 6.0 g lost in faeces
mineral ions
epithelial cells
bile pigments

- a) i) Comment on the significance of the figures for the ingestion and egestion (loss) of cellulose.
no digestion or absorption;
purely mechanical role in aiding peristalsis; (2)
- ii) Comment on the efficiency of the digestion and absorption of fats.
6 % lost ie 94 % digested and absorbed; (1)
- b) Explain the high percentage of bacteria in the faeces.
enter with the food;
bypass the sterilising effect of stomach acid;
multiply in the colon;
some lost on a daily basis and replenished by continuing multiplication in the colon; (4)

Total 7

Question 4

Study the graph showing the association of haemoglobin with oxygen and answer the following questions.

- a) i) The two curves represent the percentage saturation of haemoglobin with oxygen at two different carbon dioxide concentrations, label the curve on the diagram which is at the higher carbon dioxide concentration.
right hand curve / curve B; (1)
- ii) What effect would an increase in temperature and a decrease in pH have on the position of these curves, and what would this represent in terms of the association of oxygen with haemoglobin?
move both to the right;
represents a decrease in affinity for oxygen; (2)
- iii) With reference to the vertical arrow labelled X explain the significance of the difference between the two curves in respect of the delivery of oxygen to the tissues.
arrow X indicates difference in saturation;
at one particular oxygen level;
more oxygen released to tissues;
when right hand curve operating (high carbon dioxide); (3)
- b) Explain how the difference between the two conditions of the two curves could be increased by the activity of the body.
difference depends on different levels of carbon dioxide;
levels of carbon dioxide increased by increased respiration;
eg as a result of increased exercise; (3)
- c) Explain the physiological significance of the relative affinity (combining tendency) of:
- i) adult haemoglobin and foetal haemoglobin,
fetal haemoglobin has greater affinity;
ensures foetal haemoglobin can load with oxygen;
from adult oxyhaemoglobin in the placental artery; (3)
- ii) adult haemoglobin and myoglobin
myoglobin has greater affinity;
ensures myoglobin can load with oxygen;
from adult oxyhaemoglobin in the muscles; (3)

Total 15

Section B : Biology

Answer ALL FIVE questions in this section.

Question B

The diagram shows two cubes and their dimensions in centimetres.

- a) Calculate the surface area to volume ratio for each of the two cubes shown above.

Cube X: S.A. = 6cm^2 . $V = 1\text{cm}^3$. $\text{SA}/V = 6$

Cube Y: S.A. = 24cm^2 . $V = 8\text{cm}^3$. $\text{SA}/V = 3$ (2)

- b) i) Explain the significance of the surface area to volume ratio in relation to the exchange of substances and of heat between organisms and their environment.

substances exchanged with the environment over the surface area of organisms;

to and from the volume of the organism;

therefore the larger the SA/Vol ratio;

the more exchange capacity per unit volume; (4)

- ii) Name a structure in the typical flowering plant which is specialised to present a large surface area for exchanges.

leaf / root hair; (1)

Total 7

Question B6

The diagram is of a section through a typical leaf of a flowering plant a (mesophyte).

- a) i) Place arrow heads on the lines P, Q, and R on the diagram passing through the stomata to show the overall direction of the diffusion of oxygen, carbon dioxide, and water respectively, at noon in conditions of average humidity (3)
- ii) Give the name of a cell from which water is actually evaporating before diffusing from the stomata.
spongy mesophyll; (1)
- iii) Name the tissue in which most of the carbon dioxide that enters the leaf will be used.
palisade mesophyll; (1)
- b) With decreasing diameter of the stomata the passage of water vapour is restricted more than that of carbon dioxide. Explain the advantage of this to the plant in terms of gaseous exchanges with the environment.
primary role of open stomata is the uptake of carbon dioxide in the light for photosynthesis;
water loss an unavoidable and potentially harmful consequence;
therefore decreasing size of stomata limits the danger at less cost to the advantage; (3)

Total 8

Question B7

- a) Describe the effect on transpiration of plants living:
- i) completely submerged in water;
no transpiration; (1)
 - ii) rooted in mud at the bottom of water with floating leaves.
normal but reduced transpiration only from upper surface of leaves; (1)
- b) Describe and explain the effect of both these modes of life on the degree of development of the xylem tissue.
- poorly developed;
as xylem is the water transporting tissue; (2)
- c) One characteristic of many plants such as those above (hydrophytes) is the presence of large air spaces, especially in submerged parts. Explain the function of these.
- to allow the circulation of air to all parts;
to offset low oxygen content of water as compared to air; (2)

Total 6

Question B8

The diagrams below represent the results of ringing experiments on plants, leaves of which were exposed to radioactive ^{13}C labelled carbon dioxide and roots of which were exposed to radioactive ^{32}P labelled phosphate ions.

- a) By reference to the figures explain how this experiment demonstrates the role of phloem in the translocation of sugars and that of the xylem in the transport of inorganic ions from the roots.

in ringed plant ^{13}C compounds accumulate in the leaf from 0.10 to 0.99;

in ringed plant ^{13}C compounds do not reach roots, unringed 0.09, ringed 0.00;

in ringed plant small effect on transport of ^{32}P to the leaf from 2.2 to 1.7; (3)

- b) Studies with radioactive tracers have indicated rates of flow of sugars in the phloem of 1 metre per hour in grasses, and as high as 50 metres per hour in soya plants. Explain how this could be used as evidence against the mass flow hypothesis of translocation of sugars in the phloem.

only living phloem involved in translocation;

cytoplasm and membranes of sieve tube elements present high resistance to mass flow;

cross section dimensions of sieve tube elements do not seem large enough for mass flow at this rate; (2)

Total 5

Question B9

Give a detailed account of how gas exchange is achieved in a free living freshwater single celled organism like *Amoeba*.

small size;

therefore large surface area to volume ratio;

gas exchange over the surface sufficient to serve requirements of volume of cytoplasm;

oxygen uptake and carbon dioxide loss;

passively down diffusion gradients;

across cell surface membrane / plasmalemma;

free living organism like amoeba carry out phagocytosis by pseudopodia;

food vacuole has a surface area over which oxygen may be taken up;

and exocytosis of egested particles;

water expelled with particles carries carbon dioxide in solution;

water entering by osmosis contains oxygen in solution;

fresh water amoeba carries out extensive osmoregulation by contractile vacuole;

water expelled contains carbon dioxide in solution;

Total 10

Section H : Biology (Human)

Answer ALL FIVE questions in this section.

Question H5

- a) Explain the dangers of inhaling carbon monoxide.
combines irreversibly with haemoglobin;
competing with the transport of oxygen as oxyhaemoglobin;
reducing oxygen supply to tissues; (3)
- b) i) Explain how the unborn child of a non-smoking woman can become poisoned by carbon monoxide, nicotine and cancer causing chemicals from tobacco smoke.
by passive smoking / breathing smoker's smoke;
carbon monoxide etc absorbed into blood stream and reaches embryo across placenta; (2)
- ii) Explain the effect of tobacco smoking on the blood vessels and relate this to the lower birth weight of babies born to mothers who smoke.
nicotine constricts blood vessels;
reducing supply to placenta and embryo; (2)

Total 7

Question H6

The diagram below is of a trace from a spirometer, measuring a person's breathing.

a) Use the letters on the diagram to identify the following:

i) tidal volume,

A

(1)

ii) inspiratory and expiratory reserve volumes,

B & C

(1)

iii) vital capacity

D

(1)

b) Explain why the tidal volume can never equal the vital capacity.

impossible to move vital capacity;

repeatedly in normal breathing cycle;

(2)

Total 5

Question H7

The human placenta is of the type where there is extensive breakdown of both maternal and fetal tissues so that in some areas the maternal and fetal circulations are only separated by the thickness of a capillary wall.

- a) Explain the advantages of this arrangement.
- reduces diffusion distance between the two to a minimum;
 - increasing efficiency of exchanges; (2)
- b) Explain the disadvantages of this arrangement.
- danger of passage of unwanted substances;
 - and of mixing of two circulations as a result of leaks;
 - loss of structural attachment; (2)

Total 4

Question H8

Study the graph of heart rate and oxygen uptake of a middle distance runner performing a maximal treadmill test, and answer the following questions.

- a) Identify the periods over which:
- i) the greatest increase in heart rate and oxygen uptake occurs;
1 - 2 minutes / first minute of exercise; (1)
 - ii) the oxygen uptake continues to increase and the heart rate decreases.
14 - 15 minutes / 13 - 14 minutes after the start of exercise; (1)
- b) For the individual above identify the
- i) resting heart rate;
65 - 70 bpm; (1)
 - ii) maximum heart rate.
180 - 185 bpm; (1)
- c) Explain why the curves do not return to normal immediately after exercise stops.
metabolic demands still high;
oxygen debt;
both continue at higher rate to meet these declining demands; (3)
- d) Explain why the heart rate and oxygen uptake follow each other so closely throughout this investigation.
tissues (muscles) demand oxygen for aerobic respiration;
demand for oxygen met by increase in blood supply;
increase in blood supply achieved by increase in cardiac output which involves an increase in heart rate; (3)

Total 10

Question H9

Give an account of the effects of ageing on the skeletal system.

osteoporosis or loss of bone;
removal of calcium salts at a greater rate than replacement;
'brittle bones' leading to increased risk of fracture;
may be secondary to effect of increasing inactivity rather than ageing as such;
made worse by inactivity as stressing of bones promotes bone deposition;
weakening of musculature reduces stress on skeleton;
commonest in post-menopausal women;
linked to drop in oestrogen levels;
large genetic component in susceptibility;
osteoarthritis or degenerative joint disease;
inflammation of the synovial membrane or systemic symptoms;
loss of articular cartilage;
autoimmune rheumatoid arthritis also increases in occurrence with age;

Total 10

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 3 - Energy and the environment

Year Set 2

Time allowed 1 hour

Instructions:

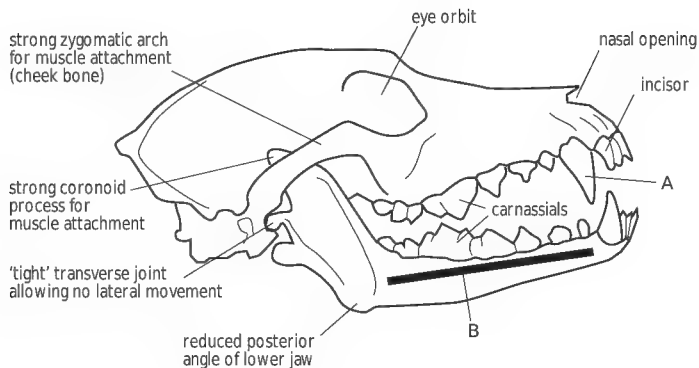
- Answer ALL THREE questions in the spaces provided.

Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 38
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question 1

The diagram below shows the skull of a dog.



- a) Describe one major problem and one major advantage associated with a carnivorous diet.

(2)

- b) For each of the structures labelled A and B briefly explain how they are adapted to a carnivorous diet.

A

B

(2)

- c) Describe how the gut of a carnivore differs from that of a ruminant.

(2)

Total 6

Question 2

About 6 000 000 tonnes of sulphur oxides are released into the atmosphere from burning fossil fuels each year. However, once released sulphur dioxide has a relative short 'residence' time of about four days in the atmosphere.

- a)** Explain how the released sulphur dioxide is removed from the atmosphere.

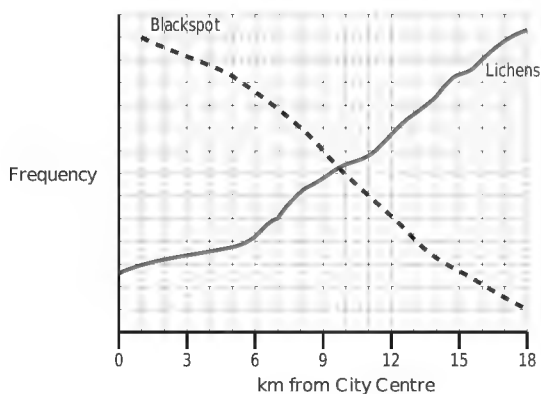
(3)

- b)** 'Clean' rain has a pH of about 5.6, and 'acid' rain can commonly have a range of pH from 4 to 6. Explain why pH figures could be misleading to the general public when attempting to describe the nature of the problem of 'acid' rain.

(2)

Question continued...

The graph below shows the number of species of Lichens, and the occurrence of the disease 'Black Spot' on roses, at different distances from the centre of a major town (lichens are sensitive indicators of the amount of air pollution in general and 'acid' rain in particular, the lichens also become 'bushier' with increasingly clean air.)



- c) i) Describe and explain the appearance of the curve for lichens.

(2)

- ii) Describe and explain the shape of the curve for 'Black Spot'.

(2)

'Acid' rain causes inorganic ions to be washed (leached) out of the soil into rivers and lakes where they reach toxic levels.

- d) i) Give one effect of aluminium ions on aquatic animals.

(1)

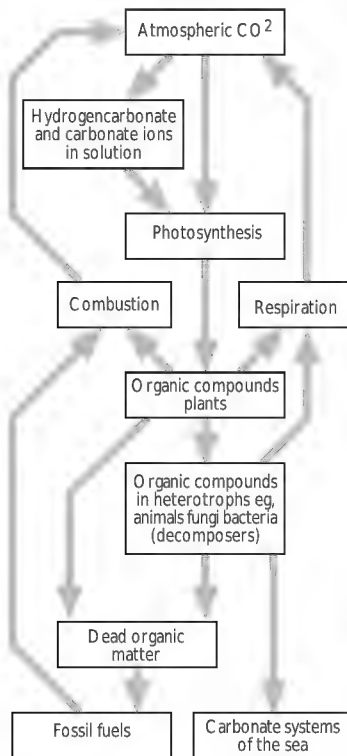
- ii) Explain why streams running off heathlands growing on acid soils have red deposits on the pebbles and are crystal clear with very few water plants.

(2)

Total 12

Question 3

A representation of the carbon cycle is shown in the diagram below.



In the carbon cycle carbon dioxide is continually feeding into and out of the atmosphere and into solution in the oceans) from the rapidly cycling pool of carbon compounds associated with organisms.

- a) i) Give two simple chemical equations representing the two major processes by which carbon dioxide is continually feeding into and out of the atmosphere from the rapidly cycling pool of carbon compounds associated with organisms.

(2)

- ii) Explain how carbon compounds pass directly between organisms in the rapidly cycling pool of carbon compounds.

(2)

The carbonate system of the sea and the earth's green belts are both 'sinks' which are very efficient at removing carbon dioxide from the air.

Question continued...

b) Explain the following terms:

i) carbonate system of the sea,

(1)

ii) 'sink' in the context of the carbon cycle,

(1)

iii) Name one sink which is now being massively exploited by humans,

(1)

iv) Name one sink which is relatively permanent;

(1)

Estimates of the amounts of carbon in the 3 major physical compartments are:

atmosphere 2300×10^9 tons;
oceans $130\,000 \times 10^9$ tons;
fossil fuels $40\,000 \times 10^9$ tons;

c) i) With reference to the figures above explain why the increasing rate of combustion of fossil fuels is a threat to the atmosphere.

(3)

In 1980 it was estimated that the combustion of fossil fuels was releasing 5×10^9 tons of carbon dioxide per year, adding 2-3 ppm each year to the air which at that date had a level of 320 ppm.

d) Evaluate the accuracy of these estimates by calculating what figure they would give for atmospheric levels of carbon dioxide today which are now 0.04 %.

(2)

Question continued...

Modern agriculture speeds up release of carbon dioxide from the soil and reduces the acidity of water, which in turn reduces the weathering of minerals in sediment based cycles

- e) i) Explain how modern agriculture speeds up the release of carbon dioxide from the soil.

(2)

- ii) Explain how modern agriculture reduces the acidity of water thus reducing the weathering of minerals in sediment based cycles.

(3)

Each year 6 000 000 tonnes of carbon dioxide are released into the atmosphere by combustion of fossil fuels, and about a third of this is absorbed by forests. Recently international agreements have been reached on the increased planting of forests to act as 'sinks' to offset the continuing high levels of carbon dioxide emissions from fossil fuels. However, this policy has been criticised on the basis that as global warming increases these forest 'sinks' will in fact become net carbon exporters.

- f) i) Explain what is meant by the term net carbon exporters,

(1)

- ii) Explain the process by which they will become net carbon exporters,

(1)

Total 20

Assessment Grid Biology and Biology (Human)

Unit 3 - Energy and the Environment

Year Set 2

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
3.1 Modes of nutrition	6									6
3.2 Ecosystems										
3.3 Energy flow										
3.4 Recycling of nutrients			20							20
3.5 Energy resources										
3.6 Human influences		12								12
										Total 38

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	0	0	Total
AO1										
Knowledge with Understanding	2	4	8							14
AO2										
Application/Analysis/Evaluation	4	8	12							24
										Total 38

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 3 - Energy and the Environment Year Set 2

Instructions

; = 1 mark / = alternative response

Question 1

The diagram below shows a skull of a dog.

- a) Describe one major problem and one major advantage associated with a carnivorous diet.
problem - piercing and tearing skin, tendon and bone;
advantage - meat highly nutritious and easily digested; (2)
- b) For each of the structures labelled A and B briefly explain how they are adapted to a carnivorous diet.
A - canines for holding, killing and tearing meat from bone;
B - carnassials sharp with scissor like action for shearing meat from bone / no chewing; (2)
- c) Describe how the gut of a carnivore differs from that of a ruminant.
shorter, vestigial caecum and appendix;
less complex; (2)

Total 6

Question 2

About 6 000 000 tonnes of sulphur oxides are released into the atmosphere from burning fossil fuels each year. However, once released sulphur dioxide has a relative short 'residence' time of about four days in the atmosphere.

- a) Explain how the released sulphur dioxide is removed from the atmosphere.
 sulphur dioxide to form sulphuric acid in air;
 catalysed by ozone and unburnt hydrocarbons;
 sulphuric acid combines with ammonia to form ammonium sulphate (a natural fertiliser); (3)

- b) Clean' rain has a pH less than 7, and 'acid' rain can commonly have a range of pH from 4 to 6.
 Explain why pH figures could be misleading to the general public when attempting to describe the nature of the problem of 'acid' rain.
 pH scale is logarithmic;
 pH4 is 100 x more acidic than pH 6; (2)

The graph below shows the numbers of species of Lichens and the occurrence of the disease of 'Black Spot' on roses at different distances from the centre of a major town (lichens are sensitive indicators of the amount of air pollution in general and 'acid' rain in particular, the lichens also become 'bushier' with increasingly clean air.)

- c) i) Describe and explain the appearance of the curve for lichens.
 more species of lichens with increasing distance from centre;
 correlated with decreasing air pollution from traffic and industry; (2)
- ii) Describe and explain the shape of the curve for 'Black Spot'.
 increasing disease of 'Black Spot' on roses at increasing distances from the centre of a major town;
 pollution decreases occurrence of the disease of 'Black Spot' on roses;
 black spot on roses prevented by $100 \mu\text{g.m}^{-3}$ of sulphur dioxide; (2)

'Acid' rain causes inorganic ions to be washed (leached) out of the soil into rivers and lakes where they reach toxic levels.

- d) i) Give one effect of aluminium ions on aquatic animals.
 sticky mucus develops on gills impairs respiration; (1)
- ii) Explain why streams running off heathlands growing on acid soils have red deposits on the pebbles and are crystal clear with very few water plants.
 red deposits of iron salts at toxic levels leached off acid soils;
 high iron toxic to plants / low organic matter therefore water clear; (2)

Total 12

Question 3

A representation of the carbon cycle is shown in the diagram below.

In the carbon cycle carbon dioxide is continually feeding into and out of the atmosphere and into solution in the oceans) from the rapidly cycling pool of carbon compounds associated with organisms.

- a) i) Give two simple chemical equations representing the two major processes by which carbon dioxide is continually feeding into and out of the atmosphere from the rapidly cycling pool of carbon compounds associated with organisms.

photosynthesis - $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

respiration - $\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$ (2)

- ii) Explain how carbon compounds pass directly between organisms in the rapidly cycling pool of carbon compounds.

by feeding, digestion, absorption and assimilation;

along food chains; (2)

The carbonate system of the sea and the earth's green belts are both 'sinks' which are very efficient at removing carbon dioxide from the air.

- b) Explain the following terms:

- i) carbonate system of the sea,

hydrogen carbonate in solution and calcium carbonate in shells; (1)

- ii) 'sink' in the context of the carbon cycle),

a reservoir of carbon into which carbon dioxide is absorbed;

thus effectively removing it from the atmosphere or in solution for varying periods of time; (1)

- iii) Name one sink which is now being massively exploited by humans,

fossil fuels / forests; (1)

- iv) Name one sink which is relatively permanent;

carbonate sediments e.g. limestone; (1)

- c) i) With reference to the figures explain why the increasing rate of use of fossil fuels is a threat to the atmosphere.

atmosphere small pool relative to fossil fuels;

carbon in fossil fuels accumulated from atmosphere and oceans over billions of years;

being returned back in decades; (3)

In 1980 it was estimated that the combustion of fossil fuels was releasing 5×10^9 tons of carbon dioxide per year, adding 2-3 ppm each year to the air which then had a level of 320 ppm.

Question continued...

- d) Evaluate the accuracy of these estimates by calculating what figure they would give for atmospheric levels of carbon dioxide today which are now 0.04 %.

lower figure would give 360 ppm ie 0.036%;

higher figure would give 380 ppm ie 0.038%; (2)

Modern agriculture speeds up release of carbon dioxide from the soil and reduces acidity of water thus reducing weathering of minerals in sediment based cycles

- (e) i) Explain how modern agriculture speeds up release of carbon dioxide from the soil.

carbon dioxide fixed by the crops does not compensate for rapid oxidation of humus by microorganisms;

as a result of increased aeration by ploughing; (2)

- ii) Explain how modern agriculture reduces acidity of water thus reducing the weathering of minerals in sediment based cycles.

carbon dioxide is acid in solution carbonic acid);

therefore its removal from the soil by agriculture reduces soil acidity;

which is normally responsible for increasing solubility of soil minerals; (3)

Each year 6 000 000 tonnes of carbon dioxide are released into the atmosphere by combustion of fossil fuels, and about a third of this is absorbed by forests. Recently international agreements have been reached on the increased planting of forests to act as 'sinks' to offset the continuing high levels of carbon dioxide emissions from fossil fuels. However, this policy has been criticised on the basis that as global warming increases these forest 'sinks' will in fact become net carbon exporters.

- f) i) Explain what is meant by the term net carbon exporters,

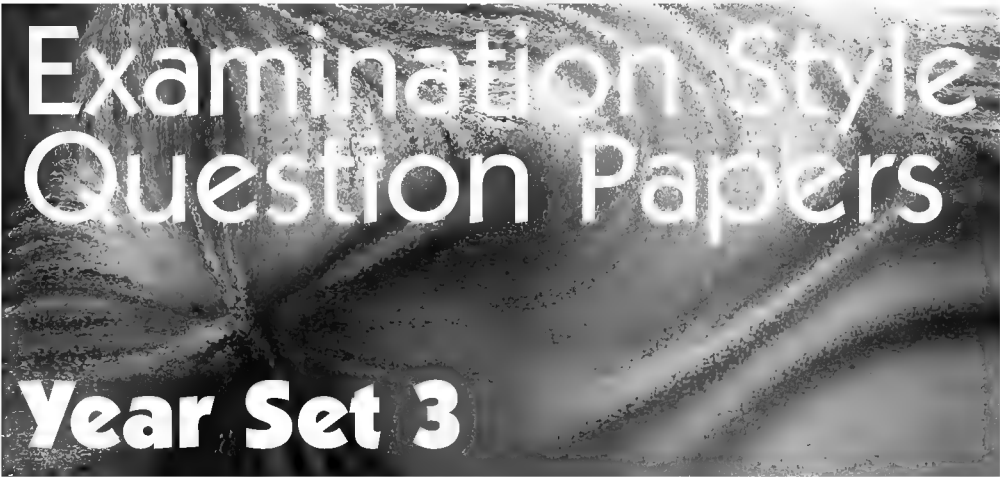
the forests will release more carbon dioxide than they will absorb; (1)

- ii) Explain the process by which the forests will become net carbon exporters,

the rate of respiration of these forests and their associated soil microorganisms will increase above that of photosynthesis; (1)

Total 20

Biology or Biology (Human)



**Examination Style
Question Papers**

Year Set 3

Unit 1 - Molecules & cells

Unit 2B - Exchange, transport & reproduction

**Unit 2H - Exchange, transport & reproduction
in humans**

Unit 3 - Energy & the Environment

Complete with Assessment Grids & Mark Schemes

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Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 1 - Molecules and cells

Year Set 3

Time allowed | hour 20 minutes

Instructions:

- Answer ALL NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- The maximum mark for this paper is 70.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question 1

- a) Plant and animal cells are both described as eukaryotic cells, describe the main features of eukaryotic cells.

(4)

- b) Name a type of organism which has a prokaryotic cell. State two differences between this prokaryotic cell and a eukaryotic animal cell.

(3)

Total 7

Question 2

- a) In the table below list three differences between the light (optical) and electron microscopes

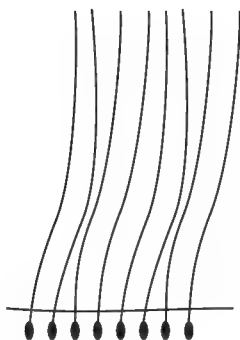
Light (optical) microscope	Electron microscope

(3)

- b) Explain the main difference between the principles of the transmission and scanning electron microscopes.

(2)

- c) Drawing X represents cilia. Drawing Y represents the appearance of a section of cilia.



X



Y

Interpret and explain the difference in appearance between the two drawings.

(3)

Total 8

Question 3

- a) i)** What is the water potential of pure water at standard temperature and pressure?

_____ (1)

- ii)** Name two factors to which the rate of osmosis is proportional.

_____ (2)

- b)** If a plant cell is placed in pure water it eventually becomes fully turgid, the cellulose cell wall can expand no further, and so no more water enters the cell. Explain this process in terms of the effect of pressure on water potential.

_____ (4)

Total 7

Question 4

A solution of unknown composition is tested with Benedict's solution and a positive result is obtained.

- a) Describe a positive result with the Benedict's test.

(2)

- b) Explain why it would be wrong to deduce that glucose was present in the test solution from the positive Benedict's result.

(3)

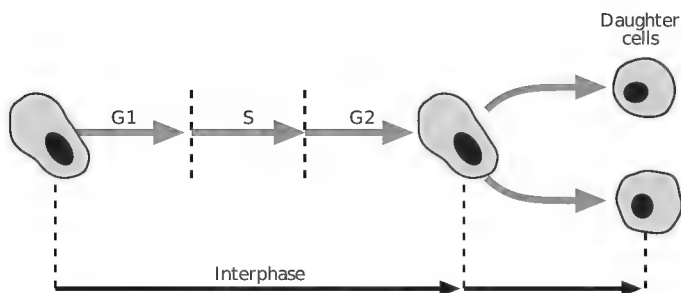
- c) Explain why it would not be correct to deduce from the positive Benedict's test result that there were no disaccharides present in the solution.

(3)

Total 8

Question 5

Study the diagram of the cell cycle of a body cell of a multicellular organism and answer the following questions.



a) Match the letters on the diagram with each of the following.

i) The period in which mitosis occurs

_____ (1)

ii) The period in which the amount of DNA doubles (replicates).

_____ (1)

iii) The point past which the cell will complete the cycle and enter division.

_____ (1)

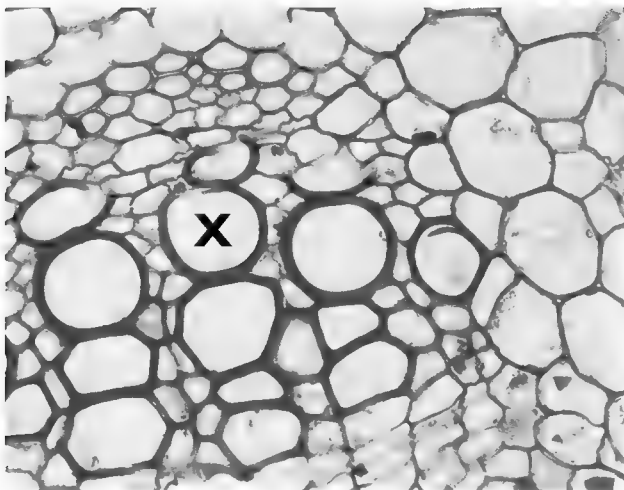
b) Explain why it is necessary for the amount of DNA to double during this cell cycle;

_____ (3)

Total 6

Question 6

The photomicrograph below shows some cells from a plant in cross section.



- a) Name the tissue marked X in the photomicrograph and describe its functions.

(3)

Question continued...

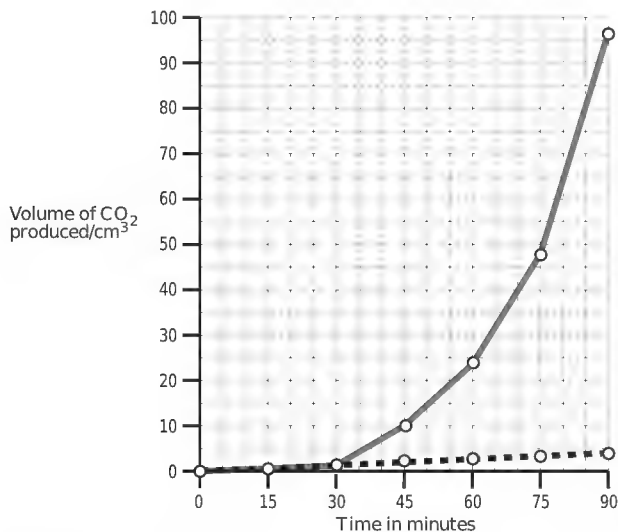
- b)** In the space below make an accurate drawing, enlarged x 1.5, of 3 cells from tissue X.
Do not label your drawing.

(5)

Total 8

Question 7

The graph below shows the rates of fermentation of two sugars by yeast (*S. cerevisiae*) as measured by the volumes of carbon dioxide produced.



- a) The term enzyme means 'in yeast' and was derived from the first experiments with yeast fermentation. Comment on the results illustrated in the graph in terms of:

i) enzyme specificity,

(2)

ii) enzymes as catalysts,

(2)

- b) Yeast cannot ferment sucrose directly but must first digest it to glucose and fructose, which can subsequently enter the yeast cells and be fermented.

explain why sucrose could not enter the yeast cells as easily as glucose.

(2)

Total 6

Question 8

Read the following passage and answer the questions that follow.

Neither the light microscope nor the electron microscope reveals much of the structure of the cell membrane. Models of membrane structure are constructed on the basis of the membrane's behaviour under certain conditions; in other words, it is impossible to separate structure and function since our knowledge of the structure derives from our knowledge of function.

Early investigations were based on studies of the rate of penetration of various materials into the cell, e.g. urea, sugars, alcohols, etc. It was found that fat-soluble substances penetrated more easily than others.

Lipids were extracted from red blood cell membranes, and the surface area that this lipid would have if it formed a layer one molecule thick was measured and found to be twice the surface area of the red blood cells.

- a) What does the fact that fat soluble substances enter the cell more rapidly than non-fat soluble substances, suggest about the nature of the membrane?

(1)

- b) What does the finding that the surface area of lipid extracted from the red cell membranes would have formed a layer one molecule thick with twice the surface area of the red blood cells, tell us about the arrangement of lipids in the red blood cell membrane?

(2)

- c) Further work indicated that 'smaller' molecules penetrated the membrane faster than would have been expected on the basis of their fat solubility alone.

What does the fact that smaller molecules penetrated the membrane faster than would have been expected on the basis of their fat solubility alone suggest about membrane structure?

(2)

- d) It has been claimed that all membranes have this common structure. Explain why the wide variety of functions shown by various membranes seems to argue against this.

(2)

- e) Why do neither the light microscope nor the electron microscope reveal much of the structure of the cell membrane.

(3)

Total 10

[illegible]

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Assessment Grid

Biology and Biology (Human)

Unit 1 - Molecules and cells

Year Set 3

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
1.1 Molecules				8						8
1.2 Enzymes							6			6
1.3 Cellular organisation	7	8	7			8		10	10	50
1.4 Cell cycle					6					6
										Total 70

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	7	5	7	5	6	8	1	3	3	45
AO2										
Application/Analysis/Evaluation		3		3			5	7	7	25
										Total 70

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 1 - Molecules and cells Year Set 3

Instructions

; = 1 mark / = alternative response

Question 1

- a) Plant and animal cells are both described as eukaryotic cells, describe the main features of eukaryotic cells.
- presence of a membrane bound nucleus at some stage in the cell cycle;
with chromosomes;
mitochondria;
chloroplastids in plant cells;
endoplasmic reticulum;
Golgi apparatus;
cellulose cell wall in plants; (4)
- b) Name a type of organism which has a prokaryotic cell. State two differences between this prokaryotic cell and a eukaryotic animal cell.
- bacterium;
no membrane bound nucleus at any stage in the cell cycle;
no chromosomes, strand of DNA only;
plasmids;
mesosomes;
cell wall; (3)

Total 7

Question 2

- a) In the table below list three differences between the light (optical) and electron microscopes

Light (optical) microscope	Electron microscope
Light (optical) microscope	Electron microscope
Uses light	Uses a stream of electrons
Objects observed directly	Objects observed via fluorescent screen
Light focussed by lenses	Electrons focussed by magnets

(3)

- b) Explain the main difference between the principles of the transmission and scanning electron microscopes.

Transmission electron microscope - electrons pass through thin sections of specimen

Scanning electron microscope - electrons reflected from surface of specimen

(2)

- c) Drawing X represents cilia. Drawing Y represents the appearance of a section of cilia. Interpret and explain the difference in appearance between the two drawings.

cilia elongated cylindrical relatively long structures;

thin sections along their length only cut small lengths;

and rarely 'catch' the connection to the cell;

giving appearance of unattached oval segments;

(3)

Total 8

Question 3

- a) i) What is the water potential of pure water at standard temperature and pressure?

0 (nought / zero);

(1)

- ii) Name two factors to which the rate of osmosis is proportional.

temperature;

surface area over which it is occurring;

water potential gradient;

(2)

- b) If a plant cell is placed in pure water, it eventually becomes fully turgid, the cellulose cell wall can expand no further, and so no more water enters the cell. Explain this process in terms of the effect of pressure on water potential.

the pressure inside the cell is raised above that in a non-turgid cell;

an increase in pressure increases the water potential;

reducing the water potential gradient to zero;

so no more water enters the cell;

(4)

Total 7

Question 4

A solution of unknown composition is tested with Benedict's solution and a positive result is obtained.

- a) Describe a positive result with the Benedict's test.

green /yellow / red;

precipitate;

(2)

- b) Explain why it would be wrong to deduce that glucose was present in the test solution from the positive Benedict's result.

Benedict's test is a test for reducing sugars;

there are reducing sugars other than glucose;

e.g. fructose, maltose, and lactose;

(3)

- c) Explain why it would not be correct to deduce from the positive Benedict's result that there were no disaccharides present in the solution.

sucrose is a non-reducing sugar;

which only gives a positive result with the Benedict's after acid hydrolysis;

positive result with reducing sugars present is an independent event;

(3)

Total 8

Question 5

Study the diagram of the cell cycle of a body cell of a multicellular organism and answer the following questions.

- a) Match the letters on the diagram with each of the following:
- i) the period in which mitosis occurs (1)
 - ii) the period in which the amount of DNA doubles (replicates);
S phase; (1)
 - iii) the point past which the cell will complete the cycle and enter division
Start of S phase; (1)
- b) Explain why it is necessary for the amount of DNA to double during this cell cycle
- two new daughter body cells are produced;
 - daughter body cells need to be genetically identical;
 - doubling (replication) of the DNA results in genetically identical daughter cells (nuclei); (3)

Total 6

Question 6

The photomicrograph below shows some cells from a plant in cross section.

- a) Name a tissue X in the photomicrograph and describe its functions.

Xylem;

transport of water;

and inorganic ions in solution;

mechanical support;

(3)

- b) In the space below make an accurate drawing, enlarged x 1.5, of three cells from tissue X. Do not label your drawing.

correct size / magnification;

correct proportions;

minimum number of cells

cell wall thickness appropriate;

accurate middle lamella;

(5)

Total 8

Question 7

The graph below shows the rates of fermentation of two sugars by yeast (*S. cerevisiae*) as measured by the volumes of carbon dioxide produced.

- a) The term enzyme means 'in yeast' and was derived from the first experiments with yeast fermentation. Comment on the results illustrated in the graph in terms of:

i) enzyme specificity,

yeast has enzymes to ferment glucose;

but not lactose;

(2)

ii) enzymes as catalysts,

glucose not fermented until enzymes present;

rapid fermentation once glucose within yeast cells;

(2)

Yeast cannot ferment sucrose directly but must first digest it to glucose and fructose, which can subsequently enter the yeast cells and be fermented.

- b) explain why sucrose could not enter the yeast cells as easily as glucose.

sucrose is a larger molecule

no specific carriers for sucrose;

(2)

Total 6

Question 8

Neither the light microscope nor the electron microscope reveals much of the structure of the cell membrane. Models of membrane structure are constructed on the basis of the membrane's behaviour under certain conditions; in other words, it is impossible to separate structure and function since our knowledge of the structure derives from our knowledge of function.

- a) Early investigations were based on studies of the rate of penetration of various materials into the cell, e.g. urea, sugars, alcohols, etc. It was found that fat-soluble substances penetrated more easily than others.

What does the fact that fat soluble substances enter the cell more rapidly than non-fat soluble substances suggest about the nature of the membrane?

the membrane is fatty in nature; (1)

- b) Lipids were extracted from red blood cell membranes, and the surface area that this lipid would have if it formed a layer one molecule thick was measured and found to be twice the surface area of the red blood cells.

What does the finding that the surface area of lipid extracted from the red cell membranes would have formed a layer one molecule thick with twice the surface area of the red blood cells tell us about the arrangement of lipids in the red blood cell membrane?

with the fats forming a bilayer;
suggests that there were two layers of lipid in the membrane;
arranged as a bimolecular lipid membrane; (2)

- c) Further work indicated that 'smaller' molecules penetrated the membrane faster than would have been expected on the basis of their fat solubility alone.

What does the fact that smaller molecules penetrated the membrane faster than would have been expected on the basis of their fat solubility alone suggest about membrane structure?

that the membrane is porous;
allowing smaller molecules to penetrate faster through pores of a certain diameter;
independent of their fat solubility therefore pores are 'aqueous'; (2)

- e) It is claimed that all membranes showed this common structure. Explain why the wide variety of functions shown by various membranes seems to argue against this.

function to a large part determined by structure and vice versa;
some functions so different as to require different membrane structure; (2)

- f) Why do neither the light microscope nor the electron microscope reveal much of the structure of the cell membrane.

the resolving power of the LM is insufficient;
the resolving power of the EM is insufficient;
preparation techniques for the EM are too drastic to leave the membrane unaltered;
molecular level too small to be revealed; (3)

Total 10

Question 9

Describe how you would set up and use a light microscope to view slides of suitable tissues.
Explain the reasons for each of your actions.

check and clean all lenses and mirrors to ensure maximum light transmission;

if microscope does not have built in illumination adjust mirror for maximum light transmission;

adjust sub-stage condenser for uniform illumination of field of view;

ensure low power lens is in place;

ensure that slide is clean, and clean if necessary;

place slide on stage of microscope, cover slip uppermost, and secure with clips to prevent movement;

focus on slide using coarse adjustment;

move slide as necessary to obtain required view of specimen;

swing next highest objective lens into position and adjust with fine control;

use of fine focus necessary now as objective lens very close to specimen;

focus away from the specimen, and if focus missed, turn back down whilst observing objective lens from side to ensure it does not touch specimen, then focus away again;

Total 10

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set 3

Time allowed 1 hour 20 minutes

Instructions:

- Answer NINE questions in the spaces provided.

Information

- The questions will score from four to twelve marks.
- You must answer Section 1 and
EITHER Section B: Biology
OR Section H: Biology (Human)
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- At least one question requires an answer written in continuous prose
- Mark allocations are shown in brackets.
- The maximum mark for this paper is 70.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

**You must answer Section I and
EITHER Section B: Biology OR Section H: Biology (Human)**

Section 1

Answer ALL FOUR questions in this section.

Question I

- a) State the name and describe the location of the nerve centre that controls breathing movements in humans.

(1)

- b) This control centre receives sensory nervous input from receptors in various parts of the body.

- i) Name and describe the location of such a receptor which is sensitive to mechanical stimuli.

(1)

- ii) Name and describe the location of such a receptor which is sensitive to chemical stimuli.

(1)

- c) i) Describe the ways in which the automatic breathing mechanisms can be overridden.

(2)

- ii) Explain what major stimulus makes holding one's breath so difficult.

(1)

Total 6

Question 2

a) Give brief descriptive definitions of each of the following terms:

i) plasma

(2)

ii) tissue fluid

(2)

iii) lymph

(2)

b) Describe how the lymph is moved through the lymphatic system back to the circulation.

(3)

Total 9

Question 3

Blood is a specialised tissue containing a number of different cell types.

- a)** Give a function of each of the type of blood cell listed below in the defence of the body against infection.

i) lymphocyte

(1)

ii) monocyte

(1)

iii) neutrophils,

(1)

iv) eosinophils.

(1)

- b)** Describe how red blood cells or erythrocytes are adapted to their function of transporting oxygen.

(3)

Total 7

Question 4

Samples of intestinal contents can be obtained by transintestinal intubation in which a tube is inserted into the gut and samples are withdrawn from different regions.

When the tube is in position a test meal of 500 g of a homogenised (well mixed) mixture of fat as corn oil, carbohydrate as glucose and lactose, and protein as milk protein is swallowed.

The meal also contains a water soluble non-digestible, non-absorbable reference substance, polyethyleneglycol (PEG).

The percentage absorption of fat, carbohydrate and protein is calculated from the relation of the amount of these substances to the PEG concentration in the test meal, and their subsequent relationship in the collected samples.

- a) i)** Describe the main difference between the test meal and a normal meal.

(1)

- ii)** Explain how a normal meal is homogenised, and the importance of this process in digestion.

(3)

- b)** The pH of the stomach was 4-5 in the first hour, decreasing to 2 in the fourth hour, whilst the pH of the duodenum was constant at 6, increasing to 8 further down the small intestine.

Explain how the pH of the duodenum and the rest of the small intestine is higher than that of the stomach.

(3)

- c)** The test meal left the stomach over a 4 hour period mostly in the second hour. The meal was diluted 3-5 times in the duodenum, and the concentration of digestive enzymes decreased along the small intestine.

Explain how the meal was diluted 3-5 times in the duodenum.

(3)

In the test meal the milk protein was labelled and used as an indicator of food protein.

- d)** Explain why it was necessary to be able to specifically identify the food protein, when it was already known to be in the meal.

(2)

Total 12

Section B : Biology

Answer ALL FIVE questions in this section.

Question B5

a) Give the main function of each of the following elements of xylem in flowering plants.

i) vessels,

_____ (1)

ii) tracheids,

_____ (1)

iii) fibres,

_____ (1)

iv) xylem parenchyma,

_____ (1)

b) Name and describe the properties of the substance with which the walls of the xylem elements are thickened.

_____ (2)

Total 6

Question B6

Briefly describe the following pathways of the movement of water across the roots of plants.

a) Apoplast pathway.

(2)

b) Symplast pathway

(2)

Total 4

Question B7

- a) i)** Explain how protandry and protogyny favour cross pollination in flowering plants.

(2)

- ii)** Explain how even if protandry and protogyny fail to ensure cross pollination, self pollination can still occur.

(1)

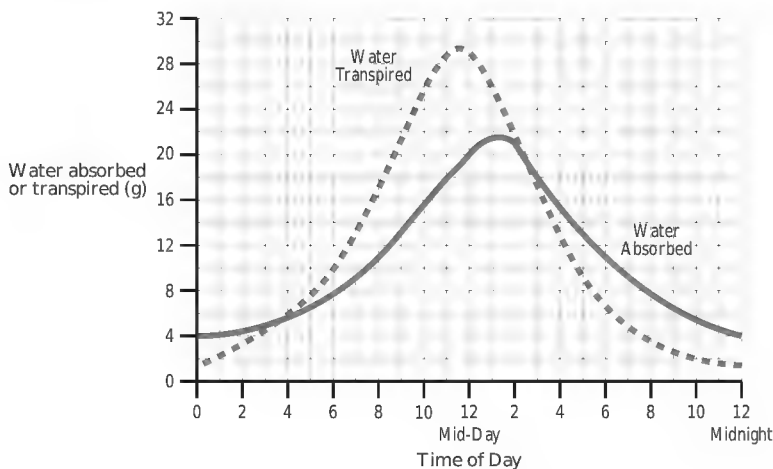
- b)** Describe an advantage of cross pollination to plants.

(1)

Total 4

Question B8

The relationship between the rate of water uptake by the roots of a plant and its transpiration rate over a 24 hour period, under natural conditions on a summer's day, is shown on the graph below.



- a) i) Identify the times that transpiration and water uptake reach their peaks.

(1)

- ii) Give one environmental factor other than temperature which reaches a peak near the time of maximum transpiration.

(1)

- iii) Explain the cause and effect relationship between the environmental factor (other than temperature) peaking and the maximum transpiration rate.

(2)

- b) Describe the environmental conditions under which transpiration could continue at a high level (at least for a short period) but water uptake is reduced to a minimum.

(2)

- c) Describe how the curves of the graphs shown at the start of the question help to explain the cohesion-tension mechanism of moving water through the xylem.

(4)

Total 10

Question B9

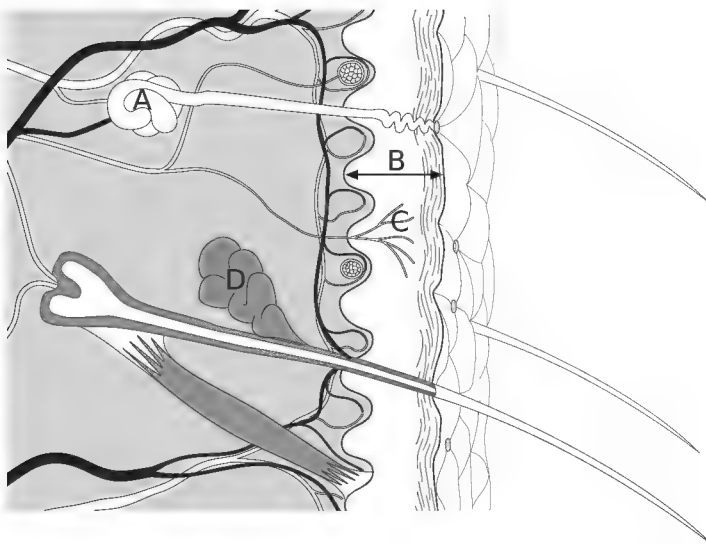
Give an account of the adaptations of flowers to insect and wind pollination.

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.**Total 10**

Section H : Biology (Human)

Answer ALL FIVE questions in this section.

Question H5



Study the diagram above of a section through human skin and answer the following questions.

- a) Identify the following structures by matching each of them with the appropriate label letter on the diagram.

i) sweat gland,

(1)

ii) epidermis,

(1)

iii) sebaceous gland,

(1)

- b) With regard to the role of the skin in temperature regulation explain the function of the sweat gland.

(3)

- c) Explain how the epidermis aids water conservation.

(2)

Total 8

Question H6

- a)** With regard to lactation and the suckling of young humans describe the origin and the role of the following hormones:

i) prolactin,

(2)

ii) oxytocin,

(2)

- b)** Describe the importance of colostrum to the suckling infant.

(2)

Total 6

Question H7

Endurance athletes make use of hypobaric (low pressure) chambers in their preparations for competition, often sleeping in them for long periods.

- a)** Explain the physiological reasoning behind this practice.

(3)

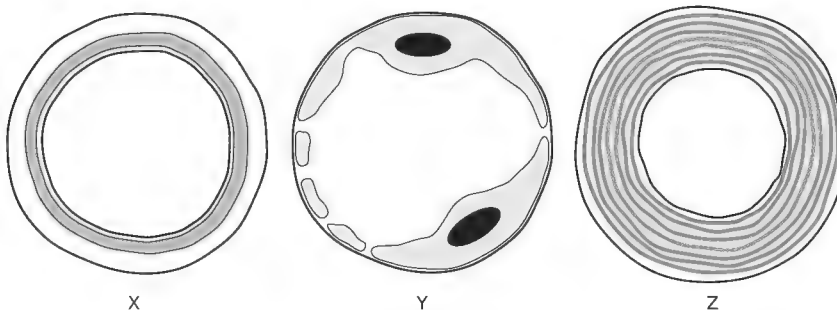
- b)** Describe what goal this technique has in common with altitude training or the misuse of the hormone erythropoietin (EPO).

(1)

Total 4

Question H8

The three diagrams below are of cross (transverse) sections of an artery, vein and capillary, not drawn to scale.



- a) i) Identify the artery, vein and the capillary.

(1)

- ii) What is the diameter of an average capillary?

(1)

- b) Describe how the structure of the capillary shown above is adapted to its function.

(3)

- c) Describe another distinguishing feature between arteries and veins that can only be seen in a longitudinal section.

(1)

Total 6

Question H9

Give an account of the effects of heat stress.

This image shows a full page of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page, providing a template for handwriting practice or general note-taking. There are no margins, text, or other markings on the page.

Total 10

Assessment Grid

Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set 3

BIOLOGY

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
2B.1 Exchanges & Environment	6			12					10	28
2B.2 Transport systems		9	7		6	4		10		36
2B.3 Adaptations & Environ										
2B.4 Sexual reproduction							4		10	14
										Total 78

BIOLOGY

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding	6	6	7	4	6	4	4	2	4	43
AO2										
Application/Analysis/Evaluation		3		8				8	6	25
										Total 68

HUMAN BIOLOGY

	Question Number									
Specification Section					5	6	7	8	9	Total
2H.1 Exchanges & Environment										
2H.2 Transport of materials								6		6
2H.3 Human ecology					8		4		10	22
2H.4 Human reproduction						6				6
										Total 34

HUMAN BIOLOGY

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	8	9	Total
AO1										
Knowledge with Understanding					3	6	1	6	3	19
AO2										
Application/Analysis/Evaluation					5		3		7	15
										Total 34

Mark Schemes for Question Paper Biology and Biology (Human)

Units 2B and 2H - Exchange, Transport and Reproduction

Year Set 3

Instructions

; = 1 mark / = alternative response

Section 1

Answer ALL FOUR questions in this section.

Question 1

- a) State the name and location of the nerve centre for the control of breathing movements in humans.
respiratory centre / inspiratory and expiratory centres in the medulla of the brain; (1)
- b) This control centre receives sensory nervous input from receptors in various parts of the body.
- i) Name and describe the location of such a receptor which is sensitive to mechanical stimuli.
stretch receptors in the alveoli; (1)
- ii) Name and describe the location of such a receptor which is sensitive to chemical stimuli.
chemoreceptor in carotid / aortic body; (1)
- c) i) Describe the ways in which the automatic breathing mechanisms can be overridden.
yawning;
coughing;
swallowing;
speaking; (2)
- ii) Explain what major stimulus makes holding one's breath so difficult.
rise in blood carbon dioxide; (1)

Total 6

Question 2

a) Give brief descriptive definitions of each of the following terms:

i) plasma

the fluid part of the blood;

dilute clear - yellow aqueous solution;

containing soluble substances e.g. inorganic ions;

containing proteins;

eg anti-bodies / enzymes

(2)

ii) tissue fluid

that part of the plasma exuded through the capillary walls;

as a result of blood pressure / water potential gradient;

minus plasma proteins;

bathes tissues directly;

(2)

iii) lymph

tissue fluid absorbed into lymphatic capillaries;

contains lymphocytes;

may contain fatty droplets from lacteals in villi in small intestine;

(2)

b) Describe how the lymph is moved through the lymphatic system back to the circulation.

contractions of surrounding skeletal musculature;

massage thin walled lymph vessels;

one way valves ensure one way flow;

(3)

Total 9

Question 3

Blood is a specialised tissue containing a number of different cell types.

- a) Give a function for each of the type of blood cell listed below involved in the defence of the body against infection.

i) lymphocyte

B cells produce antibodies

(1)

ii) monocyte

phagocytic

(1)

iii) neutrophils,

phagocytic

(1)

iv) eosinophils.

phagocytic in membranes / involved in allergic reactions;

(1)

- b) Describe how red blood cells or erythrocytes are adapted to their function of transporting oxygen.

no nucleus means that;

biconcave flattened shape increases their surface area to volume ratio;

packed with haemoglobin;

(3)

Total 7

Question 4

Samples of intestinal contents can be obtained by transintestinal intubation in which a tube is inserted into the gut and samples are withdrawn from different regions.

When the tube is in position a test meal of 500 g of a homogenised (well mixed) mixture of fat as corn oil, carbohydrate as glucose and lactose, and protein as milk protein is swallowed.

The meal also contains a water soluble non-digestible, non-absorbable reference substance, polyethyleneglycol (PEG).

The percentage absorption of fat, carbohydrate and protein is calculated from the relation of the amount of these substances to the PEG concentration in the test meal, and their subsequent relationship in the collected samples.

- a) i) Describe the main difference between the test meal and a normal meal.
test meal all 'pure' liquid 'chemicals' normal meal contains solids; (1)
- ii) Explain how a normal meal is homogenised, and the importance of this process in digestion.
mastication;
to increase surface area of food for digestion by enzyme action;
churned in stomach and well mixed with gastric juice; (3)
- b) The pH of the stomach was 4-5 in the first hour, decreasing to 2 in the fourth hour, whilst the pH of the duodenum was constant at 6, increasing to 8 down the small intestine.
Explain how the pH of the duodenum and the rest of the small intestine is higher than that of the stomach.
bile, pancreatic, and intestinal juice;
are alkaline fluids;
which neutralise stomach acid; (3)
- c) The test meal left the stomach over a 4 hour period mostly in the second hour. The meal was diluted 3-5 times in the duodenum, and the concentration of digestive enzymes decreased along the small intestine.
Explain how the meal was diluted 3-5 times in the duodenum.
food / chyme has received range of secretions;
bile from gall bladder;
pancreatic juice from pancreas;
intestinal juice from gut wall; (3)
- d) In the test meal the milk protein was labelled and used as an indicator of food protein.
Explain why it was necessary to be able to specifically identify the food protein, when it was known to be in the meal.
digestive enzymes are proteins;
their presence would raise level of protein in the gut above that due to food protein. (2)

Total 12

Section B : Biology

Answer ALL FIVE questions in this section.

Question B5

- a) Give the main function of each of the following elements of xylem.
- i) vessels,
water transport; (1)
 - ii) tracheids,
water transport (1)
 - iii) fibres,
support; (1)
 - iv) xylem parenchyma,
storage of food / waste products; (1)
- b) Name and describe the properties of the substance with which the walls of the xylem elements are thickened.
- lignin;
strong, tough, waterproof; (2)

Total 6

Question B6

Briefly describe the following pathways for the movement of water across the roots of plants.

- a) Apoplast pathway.
in the pores and channels of the cellulose cell walls of cells;
outside of the cell surface membrane; (2)
- b) Symplast pathway
passes through the cell surface membrane;
moves through cytoplasm but not vacuoles;
via plasmodesmata; (2)

Total 4

Question B7

- a) i) Explain how protandry and protogyny favour cross pollination in flowering plants.
protandry stamens mature first releasing pollen before emergence of stigmas in same flower;
protogyny stigmas mature first before stamens; (2)
- ii) Explain how even if protandry and protogyny fail to ensure cross pollination, self pollination can still occur.
overlap between maturations of stamens and stigma; (1)
- b) Describe an advantage of cross pollination to plants.
increased genetic variation; (1)

Total 4

Question B8

The relationship between the rate of water uptake by the roots of a plant and its transpiration rate over a 24 hour period under natural conditions on a summer's day is shown below.

- a) i) Identify the times that transpiration and water uptake reach their peaks.
transpiration around 12 pm and water uptake around 2 pm; (1)
- ii) Give one environmental factor other than temperature which reaches a peak near the time of maximum transpiration.
light intensity; (1)
- iii) Explain the cause and effect relationship between the peak environmental factor other than temperature and the maximum transpiration rate.
transpiration occurs mainly via the stomata stomata open in the light;
therefore the period of greatest stomatal opening and greatest transpiration is period of maximum light intensity (2)
- b) Describe the environmental conditions under which transpiration could continue at a high level at least for a short period) but water uptake is reduced to a minimum.
dry hot conditions;
soil water at a minimum; (2)
- c) Describe how the curves of the graphs shown at the start of the question help to explain the cohesion-tension mechanism of moving water through the xylem.
peak of transpiration occurs before that of water absorption;
ie water loss greater than water gain;
therefore water in xylem under negative tension;
as water pulled up by cohesion-tension; (4)

Total 10

Question B9

Give an account of the adaptations of flowers to insect and wind pollination.

insect pollinated flowers have well developed petals;

or petaloid structures;

typically highly coloured but also white and UV reflecting;

highly scented;

nectaries;

special landing areas and guides;

relatively small amounts of large spiny sticky pollen grains;

Stigma set to exploit insect movements;

insects can sometimes by-pass all this and 'rob' nectar;

also some flowers with these characteristics are self-pollinating in the bud;

wind pollinated flowers reduce petals and sepals to minimum;

exposing dangling stamens;

which produce large amounts of smooth light pollen;

typically before foliage emerges in the case of trees;

large feathery stigmas protrude out into air currents;

Total 10

Section H : Biology (Human)

Answer ALL FIVE questions in this section.

Question H5

Study the diagram of a section through human skin and answer the following questions.

- a) Identify the following structures by matching each of them with the appropriate label letter on the diagram.
- i) sweat gland, A (1)
- ii) epidermis, B (1)
- iii) sebaceous gland, D (1)
- b) With regard to the role of the skin in temperature regulation explain the function of the sweat gland.
secretes sweat onto surface of skin;
evaporates and absorbs the latent heat of vapourisation;
from the body thus cooling it; (3)
- c) In contrast, explain how the epidermis aids water conservation.
dead keratinised layer;
waterproof; (2)

Total 8

Question H6

- a) With regard to lactation and the suckling of the young human describe the origin and the role of the following hormones:
- i) prolactin,
anterior pituitary;
stimulates milk production by the mammary glands; (2)
 - ii) oxytocin,
posterior pituitary;
stimulates reflex ejection of milk in suckling; (2)
- b) Describe the importance of colostrum to the suckling infant.
- contains essential nutrients;
 - antibodies;
 - mildly laxative; (2)

Total 6

Question H7

Endurance athletes make use of hypobaric (low pressure) chambers in their preparations for competition, often sleeping in them for long periods.

- a) Explain the physiological reasoning behind this practice.
reduced air pressure reduces partial pressure of oxygen;
body stimulated to produce more EPO and therefore more red blood cells;
increasing supply of oxygen to tissues when competing at atmospheric pressure; (3)
- b) Describe what goal this technique has in common with altitude training or the misuse of the hormone erythropoietin (EPO).
stimulation of production of more red blood cells; (1)

Total 4

Question H8

The three diagrams below are of cross (transverse) sections of an artery, vein and capillary, not drawn to scale.

- a) i) Identify the artery, vein and the capillary.

X = vein; Y = capillary; Z = artery;

(1)

- ii) What is the diameter of an average capillary?

6 - 8 μm ;

(1)

- b) Describe how the structure of the capillary is adapted to its function.

thin walled / wall one cell thick;

some also have pores in the wall / fenestrated;

diameter same as that of the red blood cells;

(3)

- c) Describe another distinguishing feature between arteries and veins that can only be seen in a longitudinal section.

pocket valves in veins;

(1)

Total 6

Question H9

Give an account of the causes and effects of heat stress.

environmental factors include air temperature;
humidity;
wind speed;
amount of direct radiation;
above 30 - 32°C radiation, conduction and convection cease to aid heat loss;
contribute to heat gain;
amount of muscular activity generates metabolic heat;
which if cannot dissipate contributes to heat stress;
excessive sweating;
leading to heat cramps;
as result of mineral loss and dehydration;
heat exhaustion;
as a result of reduced blood volume;
and heat stroke;
life threatening rise in internal body temperature above 40°C;
cessation of sweating;
circulatory disruption with high blood pressure;
unconsciousness and coma;

Total 10

Examination Style Question Papers

Biology and Biology (Human)

Name: _____

Unit 3 - Energy and the Environment

Year Set 3

Time allowed 1 hour

Instructions:

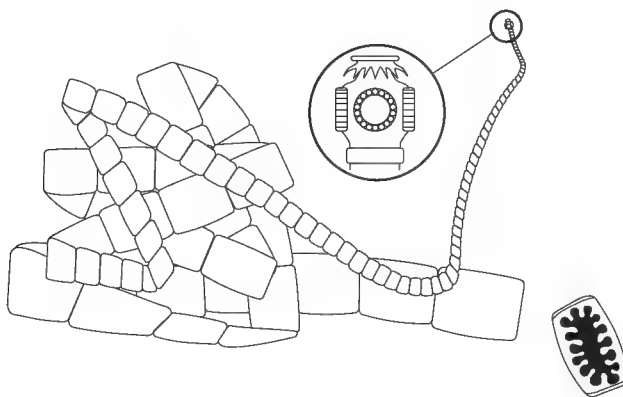
- Answer ALL THREE questions in the spaces provided.

Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 38
- The short questions will test mainly knowledge and understanding of the content of the unit.
- The longer questions will present students with stimulus material related to the specification content. These questions will also test skills of interpretation of data or information related to the content of the unit.
- Quality of Written Communication will be assessed.
- Scientific terminology should be used where appropriate.
- A calculator may be used.

Question 1

The diagram below is of *Taenia solium* the pork tapeworm.



- a) Describe how the long flat tape shape is adapted to its mode of nutrition.

(2)

- b) Name a major structure which has been 'lost' by the tapeworm as a consequence of its mode of nutrition

(1)

- c) One part of the definition of a parasite is that it does harm to its host, in this case man. Explain how the nutrition of tapeworm harms man.

(3)

Total 6

Question 2

a) Give definitions of the following terms.

i) Niche

_____ (1)

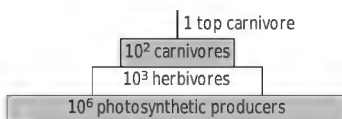
ii) Population

_____ (1)

iii) Community an interdependent collection of populations appropriate example e.g all

_____ (1)

b) The diagram below gives a simplified representation of a pyramid of numbers.



i) For this pyramid of numbers name an organism at each trophic level. All organisms must come from the same named habitat.

 _____ (4)

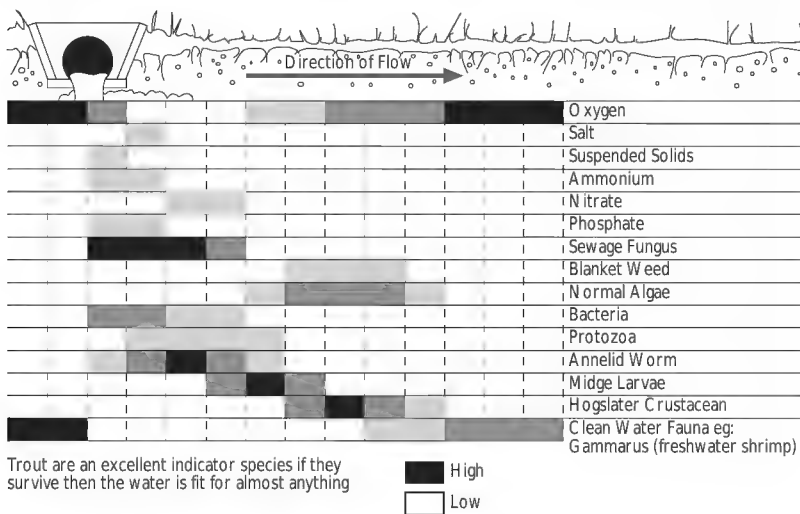
ii) Describe by reference to named organisms how a series of trophic levels in a food chain may not form a pyramid of numbers.

 _____ (5)

Total 12

Question 3

The diagram shows a representation of the effect of sewage effluent on river water and its animals (fauna).



a) Explain why presenting the data in this way is:

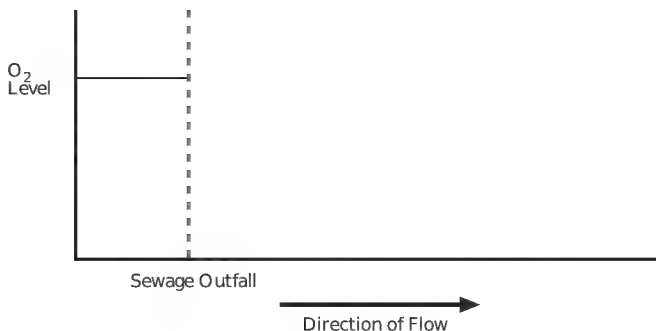
i) more realistic than drawing a smooth curve on a graph.

(1)

ii) less realistic than drawing a smooth curve on a graph.

(1)

iii) Convert the information about the levels of oxygen from the diagram into a smooth curve on the axes provided below.



(3)

Question continued...

- b) i)** By reference to the information about oxygen levels describe what is meant by “the oxygen sag” and explain its cause.

(3)

- ii)** With regard to the oxygen levels in water and the information in the original diagram, explain using examples what is meant by ‘indicator species’

(3)

- iii)** Describe the methods by which oxygen levels recover further downstream.

(2)

- c)** Explain the appearance of nitrates slightly downstream of the sewage outfall.

(3)

- d)** Explain why the sayings of “the solution to pollution is dilution” and “running water purifies itself in ten miles” are not to be believed in our urban environment.

(2)

- e)** Explain how Biological Oxygen Demand (BOD) is a measure of organic pollution load.

(2)

Total 20

Assessment Grid

Biology and Biology (Human)

Unit 3 - Energy and the Environment

Year Set 3

	Question Number									
Specification Section	1	2	3	4	5	6	7	8	9	Total
3.1 Modes of nutrition	6									6
3.2 Ecosystems										
3.3 Energy flow		12								12
3.4 Recycling of nutrients										
3.5 Energy resources										
3.6 Human influences			20							20
										Total 38

	Question Number									
Assessment Objective	1	2	3	4	5	6	7	0	0	Total
AO1										
Knowledge with Understanding	3	7	6							16
AO2										
Application/Analysis/Evaluation	3	5	14							22
										Total 38

Mark Schemes for Question Paper Biology and Biology (Human)

Unit 3 - Energy and the Environment Year Set 3

Instructions

; = 1 mark / = alternative response

Question 1

The diagram below is of *Taenia solium* the pork tapeworm.

- a) Describe how the long flat tape shape is adapted to its mode of nutrition.
large surface area to volume ratio;
for uptake of nutrients by diffusion; (2)
- b) Name a major structure which has been 'lost' by the tapeworm as a consequence of its mode of nutrition
its gut; (1)
- b) One part of the definition of a parasite is that it does harm to its host, in this case man.
Explain how the nutrition of tapeworm harms man.
robs host of nutrients;
excretes waste products into gut of host;
irritates gut of host stimulating mucus secretion which decreases absorption of nutrients by host; (3)

Total 6

Question 2

a) Give definitions of the following terms.

i) Niche

an organisms role / 'occupation';

(1)

ii) Population

interbreeding members of the same species;

(1)

iii) Community

an interdependent collection of populations;

(1)

b) The diagram gives a simplified representation of a pyramid of numbers.

i) For this pyramid of numbers name an organism at each trophic level. All organisms must come from the same named habitat.

appropriate examples of:

producers e.g. heathers in a heathland community;

primary consumers e.g. caterpillars;

secondary consumers e.g. insectivorous birds;

tertiary consumers e.g. birds of prey;

(4)

ii) Describe by reference to named examples of types of organisms how a series of trophic levels in a food chain may not form a pyramid of numbers.

any acceptable account e.g.:

single producer e.g. Beech tree;

supporting huge numbers of primary consumers;

e.g. insects and their larvae and detritivores on the leaf litter;

supporting a much smaller number of insectivorous birds;

which support larger numbers of parasites

(5)

Total 12

Question 3

The diagram shows a representation of the effect of sewage effluent on river water and its animals (fauna).

a) Explain why presenting the data in this way is:

i) more realistic than drawing a smooth curve on a graph.

water is sampled at intervals;

(1)

ii) less realistic than drawing a smooth curve on a graph.

the changes will be smoothed out by the flow of water;

(1)

iii) Convert the information about the levels of oxygen from the diagram into a smooth curve on the axes provided below.

(3)

Question continued...

- b) i)** By reference to the information about oxygen levels describe what is meant by “the oxygen sag” and explain its cause.
oxygen levels drop after entry of sewage;
caused by microorganisms carrying out aerobic respiration;
having multiplied exponentially as a result of the large amounts of organic matter in the sewage as a food supply; (3)
- ii)** With regard to the oxygen levels in water and the information in the original diagram, explain using named examples what is meant by ‘indicator species’
species which are characteristic of water with certain oxygen level;
e.g Gammarus (fresh water shrimp) is an excellent indicator species for pure water
Sewage ‘fungus’ indicates low oxygen and presence of organic matter; (3)
- iii)** Describe the methods by which oxygen levels recover further downstream.
diffusing into water at surface from air;
oxygenation by photosynthesis by algae; (2)
- c)** Explain the appearance of nitrates slightly downstream of the entry of the sewage outfall.
bacterial decomposition of nitrogen containing organic matter;
releases ammonium ions;
which aerobic bacteria convert to nitrate ions; (3)
- d)** Explain why the sayings of “the solution to pollution is dilution” and “running water purifies itself in ten miles” are not to be believed in our urban environment.
pollution load too great for dilution to be effective;
many pollutants undergo biological accumulation even though diluted; (2)
- e)** Explain how Biological Oxygen Demand (BOD) is a measure of organic pollution load.
BOD is that amount of oxygen consumed by microorganisms in a water sample;
the more organic matter the more microorganisms the more BOD; (2)

Total 20